Ethics, Psychology and Politics of Nuclear Waste Disposal

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1.0 Introduction

Many nations of the world possess or create radioactive waste and have the responsibility to manage it and, ultimately, to safely dispose of it. Of those nations, a smaller number have to contend with spent nuclear fuel (SNF) from fission power reactors and/or the high-level radioactive waste (HLW) extracted from such spent fuel by chemical processing and extraction. The radioactive component of spent fuel and HLW is an assortment of fission products unavoidably created in the release of nuclear energy from the reactor fuel. The chemical processing step which extracts the pure fission product stream called HLW is not normally done except with the objective of extracting also the valuable fissile plutonium or residual fissile uranium remaining in the spent fuel. Those nations that have produced plutonium for nuclear weapons will, of course, have stores of HLW with which to deal.

The nuclear nations have reflected time and again on the scope of the challenge of spent nuclear fuel (SNF) and reconsidered the directions of their waste research and development (R&D). In efforts to increase the safety margins, to control costs or to promote public consensus, they have often trimmed the sails to stay on an optimum course, but until now, no nation has scuttled the ship just as it was approaching the dock. But here in the United States, after decades of siting studies and over seven billion dollars invested in the Congressionally-mandated finalist, with volumes of scientific data assembled and filed in an application for regulatory review, the newly-elected President has declared without explanation that the Yucca Mountain site will not be pursued further. The Secretary of Energy has requested to withdraw the license application "with prejudice" and has charged a Blue Ribbon Commission with charting a new course – starting over. What could possibly have caused such a colossal political failure?

Had the facility proposed for Yucca Mountain been a coveted prize of industrial development like, perhaps, a movie studio or a software developer, would it have been so overwhelmingly rejected by the majority of the people of Nevada (Flynn, et al 1991) and become an albatross for elected officials? Common sense says "no." There are negatives associated with having hazardous waste facilities as neighbors. But this is true no matter where in the world the problem of SNF disposal is being addressed and, nonetheless, no other nation has "pulled the plug" on its efforts at such a late date.

Since the only competent nuclear regulatory authority (the U.S. Nuclear Regulatory Commission) has not ruled Yucca Mountain to be unqualified to meet the requirements of waste containment to protect public health and safety, the decision to abandon the project is clearly political. The Blue Ribbon Commission (BRC) has been chartered to look only at technological options other than disposal at Yucca Mountain. They are instructed specifically not to look at alternative repository sites. What then is to be expected from their recommendations? It is not technology that is the problem. It is public and political opposition to nuclear waste being transported past homes, or stored, treated or disposed of in their locale. Can the BRC devise an alternative technology that need not be sited, such that radioactive waste need not be transported? Can they devise a solution that the public will accept?

Technological achievement occurs in a social framework: it is directed toward satisfying needs, it is facilitated by historical circumstance and it is empowered by cultural traits. But it is also resisted in some cases by sectors of the public for reasons that completely elude the engineering specialists who seek to advance the technology (Pool 1997). The text that follows is written by an engineer after a studied attempt to understand what motivating forces could possibly lead to a political decision that is wasteful almost beyond precedent, plainly counter to the national interest, and contemptuous of decades of groundbreaking science. Such dramatic political decisions need public support, so the first place to look is the public perception of Yucca Mountain and why that perception is so different from the confidence of physical scientists and engineers who are experienced in this field.

After examining the roots of public opposition to hazardous waste facilities, it seems reasonable to then look closely at why so many national programs for SNF disposal have persisted in forward movement and why so many have adopted the same goal: disposal in mined cavities deep within stable geologic formations separated from flowing groundwater. A huge body of social sciences literature has developed on just these topics.

For the most part, it is rather easy to search out the thought processes and considered judgments of the scientific and engineering leaders charged with solving the problems posed by SNF and HLW management in the various nuclear nations. These nations have banded together as participants in two major multinational organizations that are meant to assist one another with the challenges of atomic energy. One, the International Atomic Energy Agency (IAEA) was formed under the auspices of the United Nations (UN). Though it's public face is more closely associated with the regulatory objectives of the 1968 Treaty on the Non-Proliferation of Nuclear Weapons (NPT or NNPT), it is also concerned with assisting member states with responsible use of civilian atomic energy. These assistance functions trace to its formation before the NPT as a response to President Eisenhower's "Atoms for Peace" initiative in December 1953. There are currently 189 signatory member states of the IAEA.

A second multinational organization that serves to assist its member states with energy matters, among many other topics, is the Organization of Economic Cooperation and Development (OECD). There are now 31 countries within the OECD, considered to be the 31 most advanced economies and industrial democracies. OECD contains within it the Nuclear Energy Agency (NEA) that organizes information exchange, studies of nuclear technology, and conferences for clarification and debate of nuclear technology issues. The NEA has published many reports of scientific consensus on these issues.

This paper intends to look closely at the commonality of approaches these member states have taken to the challenge of management and disposal of spent fuel and HLW. This suggests finding an answer to the following questions:

> Why have the scientific and policy authorities in all of these nations subscribed to disposal of spent fuel and HLW into mined cavities deep in stable geologic formations?
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> Why has monitored safe storage not been considered as more than a stopgap measure?
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> Why has the U.S. National Academy of Sciences (through it's arm, the National Research Council) encouraged isolation of such wastes from the biosphere in deep mines?
>
> Why has the Congress of the United States at least twice subordinated monitored storage to the primary goal of disposal in deep mines?

In a phrase, the answer is found in the term "intergenerational equity." It results from the moral imperative that we who have reaped the benefits of atomic energy and, in so doing, created the waste problem, must not simply hand on the problem to future generations. This paper briefly considers the origins of the concept of intergenerational equity (or justice) and how it became explicit in the field of radioactive waste disposal. This is a story of the insertion of moral values into the analysis of risk and of the increasing participation of general publics in matters that until the 1970's were the exclusive purview of business and technology.

This document does not attempt to present a complete chronology or history of the substantive achievements and setbacks of the U.S. repository program. Rather, it looks at the perceptions, motivations and judgments of participants and onlookers, as stated by themselves or discerned by social science researchers. Still, perceptions and motivations are anchored to events, so some incomplete forays into chronology are unavoidable.

2.0 Moral Imperatives and the Intuitive Dimensions of Risk

At the same time that there is a recognized moral imperative for this generation to deal responsibly with the byproducts of its industrial prosperity, including hazardous chemical and radioactive waste, potential treatment and disposal systems are almost impossible to site (Kleindorfer and Kunreuther, 1994; and Kunreuther, et al, 1996a). Once proposed for a specific location, the project begins to be discussed in neighboring communities and, more often than not, public opinion forms up in stiff opposition. Widespread public aversion then energizes the formation of interest groups and organized political opposition (Otway 1975).

Public acceptance of a technology is directly related to the public's perception of benefits and attendant risks. Just to be clear, risk refers to uncertain, but possible, unwanted costs and impacts (harms). The public employs intuitive judgments of risk, not the objective, statistical indictors of quantitative risk offered up by engineers and actuaries. Mankind has been confronting and avoiding risk by intuition for all of evolutionary time. That intuition can be fed with perceptions, values, beliefs, moral precepts and cognitive heuristics (rules of thumb) that have nothing to do with mathematics.

The disposal of radioactive waste has thus encountered challenges to justify and optimize decisions on moral and psychological considerations beyond the classical quantifiable measures of risk, cost and economic benefit. Managers and practitioners in the field, trained scientists and engineers, were largely unprepared to do this. Other modern technologies, such as genetically modified foods, food irradiation, industrial chemicals, and nuclear power have likewise attracted similar challenges.

These technologies were largely conceived, designed and implemented by technologists and industrialists unaccustomed to the participation of the general public in what they had always construed to be internal business and project management decisions. There was considerable and explicit concentration upon public health and safety by the engineers, but the general public was not prepared to accept their probabilities and assurances in matters of risk.

This dissonance between the language of physical science and the public's language and concepts of risk became salient because of the public's increasing concern and participation in matters of technology, starting with pesticides and chemical pollution. Rachel Carson's book, Silent Spring, was published in 1962 and is often credited with giving birth to environmental activism as a social force. Concern shifted to nuclear power in the mid- to late-1960s. Organized environmental interveners were in the vanguard of the public concern, and the effort largely started in California (Baumgartner and Jones, 1991).

As early as 1964, Pacific Gas & Electric had been forced to abandon plans for construction of a nuclear power station at Bodega Bay. There were two ballot initiatives or propositions to place a legal moratorium on nuclear plant construction in California. Both failed to gather the votes needed to pass. The second initiative, Proposition 15, placed on the ballot in 1975, sought to arrest nuclear power in California until 'proof' of an effective radioactive waste disposal system was forthcoming. Though this initiative failed with the electorate, the California legislature went on to enact a similar prohibition into law in 1976. (OAC 1981)

In this atmosphere of controversy, MIT Professor Norman Rasmussen published a reactor safety study funded by the US Atomic Energy Commission (AEC 1974). It was a landmark attempt to model (all possible) failure modes for a nuclear power station through what is known as probabilistic risk assessment using fault tree/event tree analysis. The study combed through excruciating details from reliability data for every mechanical and electrical component of a nuclear plant.

The Three Mile Island Accident in 1979 and Chernobyl in 1986 were widely seen to belie the AEC safety study and any other assurances based on probabilistic risk. An accident of the severity of Three Mile Island would occur once in every 20,000 to 200,000 years according to the Rasmussen safety study, but in fact it occurred after less than 500 reactor years. This was well outside of any probable inference from the risk analysis. The added factors contributing to the accident were maintenance and operator errors not included in the Rasmussen model (Giere 1991).

Only a small fraction of the general public had developed any concern for radioactive waste prior to attempts by the US Atomic Energy Commission to establish a waste repository near Lyons, Kansas. Project Salt Vault conducted a series of radiation and heat tests in the floor of an existing salt mine between 1965 and 1968. Encouraged by the results, the AEC attempted to begin repository facility development before a number of technical questions had been answered. Kansas officials became increasingly concerned that the commitment to the site was getting well out ahead of serious safety determinations that needed further research. As it happened, serious problems and ambiguities emerged with the geology and hydrology of the site. Public controversy became quite intense and was widely reported in the national press. Following this controversy, polls showed a near doubling of respondents concerned about nuclear waste (Walker 2009).

Then, in 1973, the AEC learned that about 115,000 gallons of high-level liquid radioactive waste had leaked from a near-surface storage tank at its Hanford plutonium production plant. Within a month, the *Los Angeles Times* published a critical front-page article; and a poll conduced in 1974 showed public concern for nuclear waste nearly doubling again to 52 percent of respondents (Walker, 2009).

Driven by fervent controversies over nuclear power, industrial chemicals, and environmental hazards of all kinds, academic research has produced psychological theories and cultural theories of risk perception. The cultural dimensions of risk perception involved the social science constructs of ethics, traditions, social stability, and ingrained values.

In the language of the next sections, the public perception of risk from radioactive waste had been made more acute, first by the facts, then by the emotive properties attached to the hazard, and then by "amplification" through the national media. Furthermore, research has shown that there is almost no reservoir of trust in the institutions involved in nuclear waste management that could otherwise buffer the stream of alarming images that arise in public debate (Slovic, et al 1991).

2.1 Psychological Theories of Risk Perception

Even before the Three Mile Island core melt incident, the objectivist representation of technological risk through mathematical computations of probabilities and inadvertent consequences was coming under challenge. It was very much part of the debate over nuclear power. Chauncey Starr, former President of Atomic International Division of Rockwell and (at the time) Dean of the UCLA School of Engineering and Applied Science entered the debate by writing a seminal work on technological benefits and risk (Starr, 1969). He sought to conceptualize a method for weighing technological risks against benefits in order to determine how safe was safe enough.

Chauncey Starr's paper provoked controversy and further studies, basically giving birth to the academic sub-discipline of risk perception (Douglas, 1985).

A distinction came to be drawn between risk and risk perception. Risk is the quantitative representation of what can go wrong, how often, and at what consequence (Kaplan & Garrick, 1981). When facing a decision leading to one or more uncertain outcomes, "risk" is typically computed from probabilities of occurrence and quantified physical harms. This formulation is called the "expected value" of the negative consequences. Economic models of risk replace each quantified consequence (mortalities, morbidities and property losses) by a subjective "utility" that represents how much one might care about each consequence (Renn 1992). By contrast to this cognitive analysis, risk <u>perception</u> is the intuitive judgment that people make about a risk or hazard and whether they are willing to tolerate it.

To understand how and why risk perception by lay publics differs from the estimates of formal risk assessment, psychologists question respondents, either in a controlled "lab" environment or by surveys in the home, to discern what is going on in people's brains when they encounter a decision with uncertain outcomes, including risks, and must make a judgment about it. The brain is notoriously enigmatic: its processes must be inferred and can rarely be directly measured. Behavior can be seen and measured. Even the answers given by research subjects to survey questions are a behavior. But who has directly seen an emotion, or a belief, or a thought? Researchers often arrive at distinctly different interpretations.

For example, is risk perception primarily a matter of affective (emotional) judgments or primarily cognitive? Certainly, this is a key question with regard to how to react to public opinions on technological questions. This question directly determines the real issues that must be "negotiated" between policy makers and the voting public in a democratic society.

Some researchers explain that emotions, made manifest by something called affect, precede and guide judgments and decisions [Zajonc (1980); Damasio (1994); Lowenstein, et al (2001); and Finucane, et al (2000)]. Others see the judgments and decisions to be essentially cognitive [Fishbein and Ajzen (1975); Otway and Fishbein (1976); Kahnemann and Tversky (1979); Otway (1992)]. A third understanding includes both cognitive and affective mental processing of a postulated risk, either in parallel or in an iterative cycle in which cognitive awareness of the traits of the risk leads to development of emotional reactions which, in turn, motivate and filter further cognition of risk information [Epstein (1994), Slovic, et al (2004), Sjöberg (2006)]. In this vein, a "hot cognition" concept is supported by evidence that issues, symbols, and ideas thought about and evaluated in the past become affectively charged, positively or negatively, and this affect becomes permanently linked to the concept in long-term memory. This affect then comes automatically to mind upon any future presentation of the associated object [see Lodge and Taber (2005), Bargh (1994)].

Studies of subjective risk perception have built upon the work of Daniel Kahneman (psychology) and Amos Tversky (cognitive science), who investigated biases in heuristic reasoning on matters of probability (Tversky & Kahneman, 1974), especially in the setting of games of chance and economics. Their partnership culminated in the creation of what is called "Prospect Theory" (Kahneman & Tversky, 1979). After the death of Tversky, Kahneman was awarded the Nobel Prize in Economics for his work in Prospect Theory.

Prospect theory assessed how people generally attach a value to the prospect of outcomes from decisions made in games of chance. Among the discoveries was the degree to which most people overvalue even miniscule probabilities of gains or losses (of course, the value of a prospective loss is negative). Therefore, most people are risk prone if the stakes for gains are high and risk averse if the stakes for losses are high. Tested behavior showed that the value people placed on a set of wagers could be approximated by a modified expected utility formula, where non-linear decision weights replaced the probabilities of outcomes. They discovered also an asymmetry wherein people are less willing to gamble with profits than with losses. Thus, many investors cash out winners too soon and hang on to losers too long.

Twenty years after the birth of Prospect Theory, Lowenstein, et al (2001) summarized the advancements in the study of decision psychology. Going beyond the literature of Decision Theory and survey-based psychology assessments, they also reviewed literature from clinical psychology and neurophysiology under stressful decision tests. They substantiated the role of anticipatory emotions as something subliminal: "not cortically mediated" in their terminology. They found that, almost without exception, people are sensitive to the possibility rather than the probability of negative consequences that elicit feelings of fear or worry. As the probability of a loss passes the zero threshold, a consequence that previously was ignored becomes a source of worry, no matter how small the probability. The vividness with which outcomes can be imagined is a determining factor in the strength of the emotional perception of risk. Mood and personality also have a demonstrated influence on any individual's estimates of risks and benefits. Testing shows this to be true whether the negative outcomes are a result of their own decision or a decision made by another party. Lest readers might miss the point, the authors titled their report "Risk as Feelings."

Similar conclusions were reached by Johnson, et al (1993) with respect to consumer decisions in the purchase of insurance. They found that people were willing to pay more for airline travel insurance covering death from "terrorist acts" (a vividly imaginable event) than death from "all possible causes," even though "all causes" implicitly subsumes terrorist acts in addition to a range of other causes (but does not spontaneously bring fear-provoking mental images to mind).

Paul Slovic produced one of the earliest studies of risk perception, per se, (Slovic 1964). Slovic and others continued to refine and advance psychological theories of risk perception. This work is nicely summarized in Slovic (1991) and Covello et al (1991). Because they use psychometric scaling techniques to produce quantitative measurements of risk perceptions and attitudes, they termed their findings the "psychometric paradigm" of risk perception.

In general, the psychological or psychometric models showed that people's aversion to risk is amplified to the extent that the hazard possesses certain characteristics. These characteristics play into heuristic biases by which people intuitively perceive the likelihood or severity of risk. One such heuristic is called "availability." Through this heuristic, especially vivid mental images, even from fictional movies, can cue an intuition that a similar hazard is much more likely to occur than the facts would support (Kahneman, Slovic, & Tversky1982). This heuristic is what's at work when documentary images of Hiroshima affect an individual's intuition about the likelihood and scale of nuclear power or nuclear waste catastrophes.

Paul Slovic (1986) developed the following list of hazard characteristics that figure into the intuitive gauge of risk:

Less Risky	**More Risky**
Voluntary	Involuntary
Familiar	Unfamiliar
Controllable	Uncontrollable
Controlled by self	Controlled by others
Fair	Unfair
Not memorable	Memorable
Not dread	Dread
Chronic	Acute
Diffuse in time and space	Focused in time and space
Not fatal	Fatal
Immediate	Delayed
Natural	Artificial
Individual mitigation possible	Individual mitigation impossible
Detectable	Undetectable
Old risk	New risk
Known to science	Unknown to science
Easily reduced	Not easily reduced
Individual	Catastrophic
Doesn't affect me	Affects me

For example, we might cheerfully choose to spend a day in downhill skiing, or taking a ride through the countryside on our Harley, but really resent the discovery that our water supply was contaminated with enough arsenic to pose an identical mathematical risk.

Nuclear power and radioactive waste thus have several strikes against them in the public mind. It is easy to construct catastrophic scenarios (however rare); the risk is imposed rather than chosen; and ionizing radiation cannot be felt or seen (insidious). Sjöberg and Drottz-Sjöberg (2009) and Covello, et al (1991) report further that the general public is particularly averse to risks that pose hazards to children or future generations.

Slovic, Finucane, Peters and others at the Oregon group who originated the psychodynamic model have since looked beyond the traits of the hazard itself to include factors like trust, gender, age, race, cultural predispositions, learned emotional metrics (affect pool), and stigma. These, of course, refer to the state of mind of the persons perceiving the risk and not the nature of risk itself.

Their studies were not the first to examine the influence of gender on how risks are perceived, but they are the first to concatenate gender and race; and their work has led to some controversy. That controversy is over the inferences made from the data and is instructive as to the mysteries and ambiguities of the social sciences and of psychology in particular.

First, the essence of their findings is that whites perceive less risk than people of color in a whole rage of activities and technologies. Similarly, males perceive less risk than females over the same list of hazards. Peering closer into the data, they found that the differences were due almost entirely to about 30 percent of the white males who judged risk levels to be extremely low (Finucane 2000b).

They found that the identified 30 percent had more education and higher incomes, and tested to have greater trust in institutions and authority and to have less egalitarian views. They surmised that the distinctive group of white males held social positions that gave them a sense of having more control over events. A follow-up paper (Kahan, et al 2005) inferred that the observed pattern was due to "cultural status anxiety," a state of mind in which some white males downplay risks resulting from the economic and industrial arrangements that are the source of their status. Females and non-whites feel more vulnerable due to being less empowered politically, and so risks loom larger. Two years later, the same authors published an updated version (Kahan, et al 2007) that replaced status anxiety with "identity-protective cognition" but the rationale was very similar.

It was not the data but the "cultural" explanations that became controversial. Ruth Bennett (2000) explained the challenge that came from evolutionary psychologists, quoting in particular one Margo Wilson. Dr. Wilson explains that successful mating strategies have left humans with biologically embedded psychologies, and it is an adaptive advantage for males to downplay dangers from certain types of risks. She conceded that cultural worldviews differ across racial lines in America, but says that the effects simply mask the biological gender differences. This evolutionary rationale is more fully developed in Daly, et al (2001).

This research on gender and risk is of interest here, both because gender obviously splits the voting audience that must accept nuclear waste facilities into a community, and because it illustrates the ambiguities encountered in psychology research when it comes to causal interpretations of data.

The psychometric paradigm, particularly with these subsequent extensions, has achieved notable success in terms of correlations of risk aversion with these cognitive factors. The field is still developing, however, and some experts have variant ideas about which specific emotional or attitudinal factors will yield the highest correlation to amplified (or possibly attenuated) perceptions of specific risks.

Lennart Sjöberg, a psychologist with the Stockholm School of Economics, has challenged elements of the early psychometric model. He observed that the early analyses of Paul Slovic, Baruch Fischhoff and other collaborators established correlations of hazard characteristics with sample-averaged risk perceptions and not with the responses of each individual polled. Since the variance in population averages is always less than the variance among individuals, the remaining smoothed variations are easier to correlate with the explanatory factors one is testing. This effect is known under the name of the Ecological Fallacy (Robinson 1950). Whereas the psychometric model accounts for 60 percent of the variance in average group responses to risk perception queries, it accounts for only 20 percent of individual response variance (Sjöberg 1996 and 2002).

Sjöberg insists that a useful psychological theory should work (i.e., have high explanatory power) at the level of the individual. Acknowledging his debt to the pioneers of the psychometric model, he has proceeded to look for other factors that would add explanatory power to tested metrics of individual risk perception.

The Swedish research has demonstrated a marked improvement in the psychometric model if one adds a metric for the degree to which the technology in question is seen to be "tampering with nature" or in some way "unnatural and immoral" (Sjöberg 2000a and 2000b). Nuclear power, artificial radioactivity and genetically modified foods all rank very high in this dimension and are viewed as high in risk. One other dimension adding significant explanatory power was risk sensitivity, meaning the respondent's character trait of aversion to many of life's ordinary risks (Sjöberg 2000a, 2004).

Sjöberg (2007) has found correlations of technology risk aversion with anger to be much stronger than fear. In Sweden at least, *a priori* policy attitudes about nuclear power seem to contribute significantly to variations in the perception of risk from nuclear waste (Sjöberg 1992; Sjöberg and Drottz-Sjöberg 2009). Attitudes about nuclear power, in turn, depend upon what one believes about the benefits of nuclear power, especially whether those benefits are unique or replaceable by other energy sources. In essence, if a respondent finds nuclear power to be useless, redundant, or worse, that attitude will make the risk from nuclear power waste all the more intolerable and indefensible.

It is somewhat counterintuitive to imagine that attitudes would affect perceptions of risk and benefits: one would normally think that attitudes were formed by consideration of risks and benefits. But this is confirmed in the work of Slovic, et al (2002), where they found an "affect heuristic" at work. Their findings show that favorable *a priori* attitudes about a technology cause overestimation of benefits and underestimation of risks. The converse applies if one starts with an unfavorable attitude.

Sjöberg's data also reveal some influence from "attitudes" related to political leanings and from the validations from one's circle of confidantes (Sjöberg and Drottz-Sjöberg 2008a). Evidence of this in the U.S. context is given by Rothman and Lichter (1982), as discussed in the next section.

Sjöberg finds "epistemic" trust to be a big factor. When absent, it represents a distrust of the adequacy of the science underlying safety: in effect, the experts don't know what they are doing (Sjöberg 2001). Among the Swedes polled, there was some indication that social trust (in experts and institutions) has its impact primarily by supporting or undermining this epistemic trust. In a factor analysis of public trust of Swedish institutions, Sjöberg (2008) found an interesting formulation through which competence and efficiency, normally positive traits, contribute negatively to trust in those institutions viewed as "antagonistic" to the interests of the public. Examples were advertising agencies, used car dealers, stockbrokers and politicians. Perhaps the risk is less from incompetent swindlers.

Slovic, et al (1991) examined trust as the core problem in Nevada and see a profound "crisis of confidence" by the people of Nevada (and perhaps throughout the region). According to the authors it amounts to a "profound breakdown of trust in the scientific, governmental and industrial managers of nuclear technologies." They point out the folk wisdom that trust is quickly lost and cannot be easily restored.

Trust in scientific institutions and scientific knowledge is a major factor distinguishing the experts from the lay public, with regard to risk and policy stance on the question of acceptance of a local repository. The experts also have a more positive attitude about nuclear power. Sjöberg has come to the view that, though experts perceive less risk than the public with regard to most technologies, both groups arrive at their risk estimates with the same set of contributing factors. Those factors seem to be given different weights by the different groups (Sjöberg & Drottz-Sjöberg, 2008b).

These threads of analysis have ultimately re-arranged the primary risk perception indicators into 1) perceived magnitude of consequences and 2) Anger over factors like unfairness (inequity), distrust, tampering with nature, and impacts on future generations. Peter Sandman finds "outrage" to be one of the dominant attitudes that amplify the perceived threat of a risk. Outrage, according to Sandman, encompasses factors like inequity, coercion, distrust, lack of control, and immorality (profit before safety, negligence to innocent victims, harm to future generations). Sandman pairs Outrage with Hazard, which is an undiminished image of the most severe consequences (Sandman 1987 & 1989).

When researchers first began to understand how intuitive measures of risk departed from the expected utility computations, there was a tendency to consider the lay public to be irrational, emotional and ignorant about these matters. As this work has proceeded, however, this view has shifted somewhat. For example, Slovic, Fischhoff and Lichtenstein (1981) found by more careful polling that the lay public agreed reasonably closely with experts when asked to estimate the annual fatalities to be expected from nuclear power. By this measure, a particular sample of the lay public acknowledged nuclear power to be less risky than food coloring. But when asked to estimate the expected fatalities in a particularly disastrous year, the public estimates placed nuclear power at the top of the list of activities and technologies to which they are exposed. And that turned out to be the dominant contributor to nuclear power being judged the foremost risk in the list, overall.

In 2002, Cass Sunstein coined the term "probability neglect" for the observed tendency in the general public to construct an awareness of risk that focused on consequences but to give little or no attention to probabilities (Sunstein 2002). This tendency was also reported by Lennart Sjöberg (Sjöberg 2000c).

Thus, majorities of lay public would prefer a certainty of 3 fatalities per year to a 1 in 10,000 chance (per year) of 30,000 fatalities, even though these alternatives are equal in terms of actuarial probabilistic risk (expected annual value).

The public does not seem to be ignorant of the annual record of nuclear safety: they simply will not dismiss the possibility of a disastrous accident, however remote, nor dilute the consequences to an annualized expectation value as is done by engineers and actuaries. This is typical of the results that led Sunstein to coin the phrase "probability neglect." As discussed above, the public also implicitly (at least) factors in all of the “outrage” factors of distrust, inequity, coercion, etc. in coming to an intuitive appraisal the risk.

Furthermore, it seems that scientific and engineering experts use some of the same heuristic reasoning in their own estimates of risk, when they step out of their field of expertise and must resort to intuitive measures. Richard Barke and Hank Jenkins-Smith (1993) surveyed more than 1000 engineers and scientists about their perceptions of risk and found evidence of influence from different life experience and belief systems. Biological scientists rated the risk from nuclear waste management to be much higher than did physical scientists. The result was exactly reversed when considering the risks of genetic engineering. In all cases, however, the scientists judged less risk to nuclear waste than did the lay public. Sjöberg has found much the same variations in risk perception among topical (nuclear) experts, engineers in other fields, and the lay public in Sweden (Sjöberg & Drottz-Sjöberg, 2008b).

2.2 Social & Cultural Theories of Risk Perception

The psychologist, and the psychometric paradigm of risk, operates at the level of the individual person. The psychology of individuals will find expression in the social group by social reinforcement of shared intuitive tendencies. For example, the heuristic of availability, discussed above for individuals, manifests itself in what has been called “availability cascades” in groups. Kuran and Sunstein (2007) define this as a “self-reinforcing process of collective belief formation by which an expressed perception triggers a chain reaction that gives the perception increasing plausibility through its rising availability in public discourse.” In other words, popular opinions are validated through constant repetition. This process is often furthered by the mass media.

Beyond the influence of individuals on group behavior, there appear to be patterns in individual cognition that are shaped by culture and social forces.

Social or cultural theories of risk perception start with the observation that social arrangements (determinants of rank or position in the community), ideologies, myths, values, behavioral norms all serve the survival and coherence of the group. Each human society functions within an environment and with an inheritance (cultural and material) that determines its options for a way of life - how it goes about feeding itself and protecting the group from enemies and natural forces. A chosen way of life involves the confrontation of a specific portfolio of risks or hazards. These become the familiar risks that the group is organized to confront. Any new risk that is outside that portfolio will be seen as especially threatening if the group lacks the tools and organization to confront it, or if the social status arrangements (or beliefs, or other foundations of solidarity) would have to be upended in order to confront the new risk.

Very likely the most-cited early construct of the cultural theory of risk is the work of Mary Douglas and Aaron Wildavsky (Douglas and Wildavsky 1982). Using nuclear power, carcinogen risk and other issues, they make a case for considering modern societies to be made up of a core portion which pretty much "hums along" according to the dominant paradigm, and a border portion which is made up of various sectarian interests that question particular aspects of that paradigm. Because of some, possibly narrow, alienation with the core group, the border sectarians identify with their shared critical perception and (usually) reform agenda.

Stanley Rothman and Robert Lichter have studied attitudes among the lay public and media elites and found that, among the variables they studied, "the best predictor of opposition to nuclear energy is the belief that American society is unjust" (Rothman and Lichter 1982). That certainly seems to fit with the core/border dichotomy model.

Wildavsky (1987) argues further for cultural motive forces behind variant perceptions of technological risk. He connects cultural values to the mistrust and coercion factors measured by psychologists. He sees two primary dimensions of cultural differentiation determined by 1) whether there is strong group identity (with loyalty and sharing) or else weak social networks leaving individuals to competitively fend for themselves, and 2) whether the individual is subject to few or many behavioral prescriptions imposed by authorities. This two-dimensional view of culture is called the "Grid-Group" typology.

Four broad types of cultures result: Fatalistic (atomistic and hierarchical), Individualistic (atomistic and libertarian), Collectivist (group cohesion and hierarchical authority), and Egalitarian (group cohesion and voluntary consent). Some small societies can be largely of one type or the other, but complex modern democracies have coexisting subcultures of each of these types. Where free to do so, citizens will gravitate into whichever subculture best comports with their vision of an ideal social life.

In this view, egalitarians oppose technological risk because they see it as imposed by powers of industry and government hierarchies that they don't trust. The subcultures that are more comfortable in hierarchical arrangements (military, industrial, etc.) see the risks as thoughtfully chosen by respected authorities, so therefore not illegitimately imposed. Libertarian individualists often see technology as a triumph of free markets and are more accepting of the risks, but they may quickly react to the exercise of eminent domain or Federal preemption, which they see as coercion from government that they don't trust. Wildavsky (1987) summarizes:

> "Put briefly, we contend that the debate over risk stemming from technology

> is a referendum on the acceptability of U.S. institutions. The more trust in them, the more risk acceptance; the less trust, the more risk rejection."

The Douglas-Wildavsky model has been criticized for its oversimplified social typology and its labeling of environmental groups as "sectarian" outliers of society. Steve Rayner (Oxford University via prior positions at Columbia University, Pacific Northwest Laboratory and Oak Ridge) was a leader in refinements to the simple center-border dichotomy and postulated that the risk factors most people care about, aside from potential harms, are trust, liability and consent (Rayner 1992). These are posed as questions that beg satisfactory answers:

1. Are the institutions that develop, manage and regulate the technology worthy of fiduciary trust?
2. Will liabilities for an undesired consequence be apportioned in a manner acceptable to those affected?
3. Is collective consent obtained from those who must bear the consequences?

As regards the problem of nuclear waste facilities, cultural theorists look for attitudes about social structure that might drive an amplification of the aversion to that risk. For example, hostility or suspicion of for-profit enterprise, especially in matters of safety and environmental protection, will tend a like- minded group of people to oppose a for-profit project that could be the source of industrial hazards. Similarly, suspicion of the incompetence or "political" motivations of government elites will animate opposition to a government project on the basis of amplified perception of risk.

Such a group might coalesce around evidence of inequitable distribution of the project benefits and consequential risks. Research has shown that the public perception of technological and industrial risk is moderated by awareness of attendant benefits. But if the benefits flow to one group of people and the risks to another, then an inequity or injustice is born. If it is felt that the inequity is the result of government policy, then those people "unfairly" burdened with the risk feel betrayed by a violation of the social contract for government to be evenhanded (Koehler and Gersoff 2003). They are doubly alienated from the "core group" and likely to exert a particularly intense opposition that is powered by moral fervor.

This description fits the reaction of many in Nevada to the Nuclear Waste Policy Amendments Act of 1987 (NWPAA), in which the Congress determined that federal resources should be focused on the one leading technical site (at the time), namely Yucca Mountain, Nevada. The NWPAA was almost immediately referred to as the "Screw Nevada Bill" by opposition groups, Nevada political leaders, and the local media (Kanigher and Manning, 1998).

The public record is replete with public and political comments questioning the fairness or equity of any western repository site when the benefits of nuclear power flow predominantly to the eastern United States (Carter 1987). It doesn't seem "fair" that the spent fuel hazard would be removed from the power plant sites, whose neighbors profited from clean, dependable and inexpensive nuclear power, and relocated so as to be imposed on the neighbors of the centralized repository. So, it is not clear that any centralized national repository could avoid the same fairness issue and the resulting aggressive public and political opposition.

One factor might alleviate that sense of unfairness: the belief that the chosen site and the facility itself are the "best" of all plausible alternatives to solve a national problem (Easterling 1992). It would be a case of civic duty trumping self-interest. This might well be a fragile hope upon which to build a plan for centralized disposal. There may be suggestions of this civic duty impulse in social sciences survey data, but hypothetical statements of intent to support a "best" site found in one's own backyard might not be sustained in the real event.

It is worth mentioning at this point that the most-often considered alternative to permanent disposal in deep mined repositories is some sort of centralized above ground or near-surface monitored retrievable storage (MRS). The same fairness issue applies to MRS site selection, but its advantage of freedom from specific geologic requirements disallows any claim that a chosen site is the "best" among available alternatives. Thus, any appeals to civic duty and altruism will fall on deaf ears.

In fact, after the failure of the repository proposal for Lyons, Kansas, the AEC opted for retrievable storage and floated a draft Environmental Impact Statement (EIS). The proposal received poor grades from environmental groups, state and local governments, and the U.S. Environmental Protection Agency (EPA). The critics argued that the MRS concept just deferred progress toward permanent disposal and created a risk that the interim measure would default to a permanent inadequate arrangement. The idea was dropped (Zinberg 1982 and Greenwood 1982).

Another MRS proposal was floated by the Department of Energy (DOE) in a 1985 MRS study report required by the NWPA of 1982. All proposed sites were near Oak Ridge, Tennessee. After a series of DOE-funded independent studies by Tennessee agencies, the Governor announced his opposition in 1986. After some State/Federal legal wrestling, the proposal became moot when swept up in the major changes of the NWPAA of 1987 (Colglazier, 1991). It seems that state officials are keenly aware of former Governor (SC) Richard Riley's "first law of political physics, often overlooked…, which says that waste stays where it is first put" (Riley, 1982).

Roger Kasperson, Research Professor of Geography at Clark University (Worcester, MA) is a prominent contributor to the development of risk perception theory, especially as relates to environmental protection. Dr. Kasperson has long been a member of the Boards and Committees of the National Academy of Sciences that were consulted on matters of radioactive waste management. Kasperson and his wife, Jeanne, have studied the peculiar fact that some significant hazards remain totally under the public radar until they have taken a serious toll. They mention asbestos insulation among several such "hidden hazards" and point also to the morbidity toll of coal-fired power stations that gets far less attention than the low-probability risks of nuclear power. Risks that elicit insufficient concern, despite scientific evidence and even medical impact, can be said to be "attenuated" both by the society's agencies of awareness (e.g., media) and by individual cognition.

The Kaspersons teamed with Slovic and others to study the social "amplification" of certain risks, including those of radioactivity and hazardous facilities. They note that risk information is processed through "amplification stations" that include the news media, partisan activists, public agencies, social networks (the rumor mill) and the scientists themselves. Due to this amplification, communities across the United States have opposed nuclear facilities, prisons, refineries and waste incinerators regardless of safety assurances. The work in these areas is well summarized in Kasperson (1991 and 1992).

A good example of news media amplification is the New York Times Book Review of Rachel Carson's "Silent Spring," in which the reviewer exhorts readers to appreciate that "people today are being poisoned on a scale that the infamous Borgias never dreamed of" and "It is high time for people to know about these rapid changes in their environment, and to take an effective part in the battle that may shape the future of all life on earth." (Milne, 1962) Appendix A discusses how a particular description of the hazards of fission product waste serves to "amplify" the public perception of the risks.

Kunreuther and Slovic (2001) build off of the concept of social amplification to discuss the phenomenon of "stigma" as it is attached to risks from products, facilities and activities. Stigma motivates avoidance, and several cases are presented, including a study of the potential for Yucca Mountain to stigmatize Las Vegas. One national survey found that 12 percent of respondents would actively protest the siting of a HLW disposal facility if it were even 1000 miles away (Easterling and Kunreuther 1995 and Flynn, et al 1990). That figure rose to 50 percent at a distance of 200 miles. Slovic (1992) presents some very discouraging data on negative imagery conjured up in response to the phrase "Underground Nuclear Waste Storage Facility." There were hundreds of negative associations, and not one positive. It is clear from the associations that they would attach to nuclear waste in whatever form, and not restricted to “underground.” For more detail on these studies of stigma, see Slovic, Flynn and Layman (1991). Public acceptance will be very hard to attain.

A series of reports from the U.S. National Research Council (National Academy of Sciences) has assessed the studies of risk perception and commented upon the accommodation of values and perceptions in public policy. Its first report (NRC 1983) describes the relationship of science to political policy, noting that science informs risk assessments that in turn inform the decisions taken in risk management. A second report (NRC 1986) examines the issue of fairness in the distribution of risk and the role of mitigation and compensation in risk management. The third report (NRC 1989) noted the role of cultural values in risk perception and communication. The final report (NRC 1996) discusses how values need to be taken into account early in decisions affecting risks imposed on the public, and recommends early and earnest dialog with public stakeholders. There are many more NRC reports on applications of the art and science of risk to health care, toxicology, air and water pollution, military and space operations, and other areas.

Social and cultural influences on risk perception find expression in the political sphere in democratic countries. Carter (1987) and Colglazier (1982) do a particularly good assessment of political themes and policy making prior to the passage of the NWPA of 1982. Luther Carter’s book, being published 5 years later, bears witness to the constituent forces and negotiations that played directly into the legislation. Both books describe U.S. nuclear waste history as a technology-driven effort that was undermined by institutional complexity (too many actors), reluctant resourcing, naïve optimism, irreconcilable policy differences among stakeholders, the gaming of hidden agendas, wavering policy commitments by Federal players, almost universal public opposition to local facilities, and fragile political will.

Easterling and Kunreuther (1995) provide a fairly thorough assessment of the public psychology, political responses and policy adjustments occurring during the period between the NWPA of 1982, through the NWPAA of 1987, and up to the publication date of their book. They report on an effort, of which they were part, to develop guidelines for a noxious facility siting process optimized to gain public acceptance. They temper their endorsement of the process with respect to HLW repositories due to results of their own research. Their studies showed that direct compensation could be ineffective or even counterproductive, and that “no amount” of mitigation may convince the public of safety of nuclear waste. Nonetheless, they see a path forward only in beginning anew with first building a national consensus on two points: 1) the status quo is unacceptable, and 2) Method X is the solution that best addresses the problem. Among the other guidelines is the suggestion that the siting process be made voluntary for states and local communities. Interestingly, all of their prescriptions for successful siting are phrased as necessary but not sufficient conditions (an effort cannot succeed unless…). Since we in the United States currently do not have a national consensus on almost any meaningful topic (gun rights and regulation, health care reform, credit crisis response, offshore oil drilling, immigration, etc.), it takes a great leap of utopian faith to hope for consensus and consent with respect to radioactive spent fuel management.

The DOE nuclear waste disposal program is not the only Federal activity to encounter many of the conflicts and challenges mentioned here. The cleanups of contaminated Federal lands, principally those of DOE and DoD, are together referred to as the Federal Facilities Environmental Restoration programs. There have been frequent disputes between the agencies and any number of stakeholders, including state and local governments, environmental interveners, and neighboring property owners. These disputes involve priorities, the funding and pace of cleanup, residual contamination and ultimate land use. The U.S. EPA is the regulator and has tried to mediate these disputes. The EPA convened a Keystone Federal Facilities Dialogue Committee with representatives of all parties. Public and local government participants insisted upon broader considerations of cultural values and other factors lying outside of the traditional risk measures. The Committee settled upon a "risk plus other factors" approach to funding priorities, and participants agreed that, in certain instances, factors that have very little to do with human health risk may become the overriding factors in setting cleanup priorities (US EPA 1996).

2.3 Does Scientific Risk Assessment Constitute Ground Truth?

Thus far, we have observed that public perceptions of technology risks differ considerably from expert risk assessments, and we have reviewed the social sciences findings on how lay public risk perceptions are constructed. The very wording of this review has implied that the magnitudes of risk as computed by experts has a scientific claim to truth, while the lay public can lay claim only to "perceptions" that differ from this presumed truth.

Anyone taking a plunge into this topic will quickly realize that risk is not quite the objective entity that one might have assumed. At the core of any risk is a hazard that is objectively real. Hazards are generally taken to be situations, events or physical things or substances that can cause harms. Examples might be cliffs, quicksand, crocodiles, or chlorine gas. Hazards have attributes that can be observed and measured: location, size, mass, velocity, chemical or radiological toxicity, aggressive behavior traits (like crocodiles). They are real enough. The harm suffered as a result of encountering the hazard (loss of a leg to the crocodile) is also real enough. But the risk associated with these hazards is an inference related to the possibility of harm from an encounter with the hazard. Strictly speaking, neither an inference nor a possibility can be considered an objective reality. For more on the philosophy behind concepts of risk see Renn (2008), Rohrmann (1998), and Shrader-Frechette (1991).

When we formally analyze risk, we construct numerical measures like the annual expected value of fatalities. This is a measure of great use to life insurance companies. It has an embedded value that all lives count equally. But what if we computed the loss of life expectancy, years of life denied by each fatality. This measure has the embedded value that the old do not count as much as the young. The importance of these embedded values becomes evident if we envision choices being made according to the ordinal ranking of risks computed in these two ways. For example, the allocation of Federal research funding among geriatric diseases (Alzheimer's, prostate cancer) and pediatric diseases (Huntington's, Cystic Fibrosis) would depend strongly upon the method of risk computation.

Most social scientists and many physical scientists take the view that formal risk assessments are <u>not</u> rigorously objective representations of the truth except in almost trivial cases. Take the case of the risks from traffic accidents. The risk can be computed as the probability of occurrence multiplied by a magnitude of adverse consequences using real, historical frequency data for collisions per mile driven and real frequency data for the fraction of collisions resulting in fatalities and injuries. Providing that there has been no change in context factors like weather, road surfaces, age distribution of drivers (demographics), etc., computations using most-recent data may still be accurate. Let's say that data trend lines have been flat for two years.

Now, let's make this personal. You are a certified traffic engineer; you have a Master's degree in actuarial statistics and 20 years experience. You know where to find the good raw data, and you use proven techniques to develop numbers for expected fatalities, injuries and property damage, and the data are good enough to establish 95 percent confidence intervals on the estimates. Your results are data-driven, they are replicable by independent assessors, and they are falsifiable. Your risk assessment is <u>scientific</u>.

Your client is a car insurance company that needs a two-year projection of potential claims in order to set aside reserves against those payouts. They need your best estimate, and you have a fiduciary responsibility to provide it. It's December 2008. Lehman Brothers has dissolved in bankruptcy, banks have ceased lending to one another, the Dow is down to 7600, and the sitting President has convinced the Congress to give him $700 Billion to bail out the banks that have gambled away their balance sheets. Your Rotary friends tell you that they can't get cash-flow loans to finance inventory and payroll. Imagine, a conservative President, and he's forgotten that government intervention won't work. It's a misallocation of capital. And the incoming President promises more of the same.

Unemployment is already at 8 percent. Your intuition tells you that businesses will further retrench in the face of government meddling, and unemployment will hit 15 percent in 2009. And every unemployed person has three friends who will worry that they may be next. You know that higher unemployment and job insecurity leads to increased use of alcohol and increased DWI (Driving While Intoxicated). You boost your estimated risks for motor vehicle harms by 20 percent.

Your new estimate may be a better estimate of what will in fact happen, but it is no longer entirely <u>scientific</u>. You are not a qualified economist, nor a substance abuse expert, so a portion of your estimate is <u>intuitive</u>. It has resulted in part from cognitive heuristics rooted in your values and beliefs. Your estimate may well be better than the risk perceptions of casual observers. But it is not entirely different in kind.

The problem is more complicated when there are scant or no frequency data for the potential harms posed by most technologies. Exposure probabilities and morbidity responses must be constructed by experts through a process that is not falsifiable.

For example, low-level chemical or radiological carcinogen risk cannot be obtained without the exercise of educated expert judgment. We can't create controlled data for exposure of human subjects to carcinogens, so we use animal data. Translation from animal dose-response curves to humans requires expert judgment. Judgment can vary among experts. Even the data that can be practically obtained from rodent experiments has wide uncertainties, as observed by Alvin Weinberg in his essay on "Science and Trans-Science" (Weinberg, 1972). He worked out that to determine by direct experiment the genetic mutation rate in mice, at the 95 percent confidence level, under an exposure of 150 millirem of ionizing radiation (about one-half of average annual background and six times the allowable fence line dose at a licensed nuclear facility.), would require 8 Billion mice. Needless to say, that has never been done. He goes on to discuss how the risk from extremely improbable events cannot be determined by strictly scientific method and cannot be falsified. These estimates, according to Weinberg are in a domain of trans-science.

There are data that show expert judgment to be less than reliable. For example, Mandl and Lathrop (1983) compared ten independent studies (by acknowledged experts) of the risk to communities neighboring liquefied natural gas (LNG) terminals in four countries. The plant designs and operating modes were very similar, but due to assumptions made in the assessments the risk estimates varied by a factor greater than 1 million. In the same vein, Amendola (1986) reports that teams from ten countries assessed mean failure probabilities varying by a factor of 45 for the auxiliary feedwater system of the same French nuclear power plant.

Almost all of the first-tier experts in risk agree that formalized risk assessment is not a value-free, scientific representation of objective reality. But it is the nearest approximation available. Many have taken to using the term "formal" risk assessment, rather than scientific or objective, because it is the formal analytical conventions that reduce subjective judgment to a minimum.

The more central position in the debates about validity of formal risk assessment and intuitive risk perception is the one taken by Otway (1992). He compares the formal analysis of the engineer with the intuitive perceptions of the lay public and finds they differ primarily in terms of scope. The public simply cares about more than the level of risk, per se. They also care about qualitative aspects such as who is exposed, who gets the benefits, what institutions are favored by the particular technology, what the catastrophic accident potential is, etc. He observes that "you can quite rationally oppose a technical system that engineers have certified as 'safe' if it turns out that their definition of 'the system' did not include the things you care about most." He further points out that when problems are defined in such a way as to make them the exclusive province of experts, it is a way to shut out the public from any contribution. The public sees this as antidemocratic and resents it. Otway's only concern about formal risk assessment seems to be the quality of the expert judgment and the assumption that it is the only worthwhile consideration.

Some social scientists have gone so far as to claim that subjective risk perception is more legitimate than formal statistical estimates of risk. This assertion attracts significant controversy. Of course, perceptions are very real to those who hold them, and anyone attempting to site a noxious facility needs to anticipate and contend with public perceptions as fact. But it is not necessary to accept them as transcendent revelation. One contributor in particular has warned about the social dangers of elevating perceptions above scientific risk estimates (Frank B. Cross 1992).

Appendix B includes some quotes from Dr. Cross' analysis. At root, he shows how subjective risk perceptions, being rooted in emotion and opinion, can be more readily manipulated than risk estimates anchored in scientific method. To dispel any doubt on this point, consider the manipulations of consumers by modern marketing, as an example. It will not be the average consumer who would invest huge sums in TV spots and lobbyists and hired pundits in order to mold public opinion. It will be those who have large profits hanging in the balance. If one can manipulate perceived risk, and it is given primacy over science-based risk estimates, then one can shift the attention of regulators in any way desired. He points out the irony that the subjectivists on this point want to empower the public against what they see as science in the service of elites who understand it and can sponsor it. This is a kind of myopia in which only the first move of the chess game is seen.

3.0 Intergenerational Equity As a Lodestar for HLW Disposal

Of the psychological and cultural factors discussed above, those of control over the risk, whether it is voluntary or imposed, and the burden on children or future generations, speak to cultural values of fairness and justice. Intergenerational equity has been confirmed as one of the important psychological factors influencing the perception of risk (see Slovic 1991 and Sjöberg 2009) and therefore a factor to be considered in any assessment of risks and benefits associated with waste management and disposal.

Because fission product waste retains its radiotoxicity for generations, and since our moral compass leads us to perceive a possible hazard to future generations in more vivid hues, so therefore protection of future generations must be the central purpose of a centralized waste repository. Confidence that a specific repository project in a specific location can do that is key to public acceptance.

The protection of future generations of mankind has always been implicitly central to the goals of permanent disposal of spent nuclear fuel (SNF) and High-Level Radioactive Waste (HLW). Hence the long time frames for assuring isolation of the waste from the biosphere. In several places, the objective has been written into law. The Nuclear Waste Policy Act of 1982 (NWPA) contained the Congressional finding that:

> "High-level radioactive waste and spent nuclear fuel have become major subjects of public concern, and appropriate precautions must be taken to ensure that such waste and spent fuel do not adversely affect the public health and safety and the environment for this or future generations."

This was no casual statement. Much of the Congressional maneuvering and negotiation over the provisions to be put into the NWPA of 1982 explicitly weighed the options of long-term, monitored retrievable storage against permanent disposal. The NWPA was a thoroughly deliberated statement of a national policy of permanent disposal (Carter 1987). Altogether, the intent of Congress was clear.

The Repository Siting Guidelines developed by the US DOE in response to requirements of the NWPA of 1982 were issued as Part 960 of Title 10 of the US Code of Federal Regulations, and thus had the force of law. The recognition of future generations was explicit with respect to avoidance of inadvertent intrusion. Aside from the specific considerations, a general principle was stated as:

> "The site shall be located such that activities by future generations at or near the site will not be likely to affect waste containment and isolation. In assessing the likelihood of such activities, the DOE will consider the estimated effectiveness of the permanent markers and records required by 10

CFR part 60, taking into account site-specific factors, as stated in §§960.4–2–8–1 and 960.4–2–8–2, that could compromise their continued effectiveness."

The United States has even signed a treaty that commits us to permanent disposal. By signing and ratifying the UN Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management (Joint Convention) (IAEA, 1997), the United States agreed to its terms. Notably for the purposes of this paper, these terms include the following obligations:

- strive to avoid actions that impose reasonably predictable impacts on future generations greater than those permitted for the current generation;
- aim to avoid imposing undue burdens on future generations.
- ensure that during all stages of spent fuel and radioactive waste management there are effective defenses against potential hazards so that individuals, society and the environment are protected from harmful effects of ionizing radiation, now and in the future, **in such a way that the needs and aspirations of the present generation are met without compromising the ability of future generations to meet their needs and aspirations** (emphasis added).

These treaty provisions have been made tenets of American law by ratification. It will be seen in subsequent text that the protections afforded to future generations are precisely the driving motivation to sequester our spent nuclear fuel and HLW in ways that securely isolate the waste from the biosphere. It is this ethical dimension that argues against our placing our faith in monitored retrievable storage, which would burden future generations with the diligent monitoring and continued maintenance of the storage regime and the continued need for choosing sites and engineering the permanent disposal facilities.

If a signatory to this Joint Convention has not yet found an adequate site within its national boundaries but is still dedicated to that objective, it can be judged by its evident intent to comply. The current situation within the United States is, however, arguably in contravention of the Joint Convention and, by inference, of United States law. In Yucca Mountain, we have a chosen site and a proposed system in regulatory review, and yet an overt decision seems to have been made to abandon that disposal option. This decision will, of necessity, impose the entire problem upon a future generation and possibly two generations beyond that. Remember that Yucca Mountain was first added to a mix of sites under study in 1976, following a recommendation by the U.S. Geological Survey (see USGS 2005). That's 33 years ago, and judging by the retirements of most of those involved at that time, Yucca Mountain has already absorbed a full generation of effort.

We have seen that projecting risk upon future generations is an important worry among those who have deep reservations with radioactive waste facilities. We shall see next that intergenerational equity is in the forefront of the moral thinking of every nuclear nation, and that all are moving resolutely toward geologic disposal. What is the history of this notion of intergenerational equity that it should play a prominent role in an international treaty on responsible management of nuclear waste? That is the subject of the following sections.

3.1 IAEA and HLW Disposal

The coordinating agency behind the Joint Convention was the International Atomic Energy Agency (IAEA). Its concern for considerations of the interests of future generations was expansively explained in a 1996 document (Issues in Radioactive Waste Disposal, IAEA-TECDOC-909), which reported on the findings of an International Working Group on Principles and Criteria for Radioactive Waste Disposal. Typical of such working groups, this one had 38 experts from 12 member countries making up the collective authors of the report. This report took cognizance of earlier work from the OECD Nuclear Energy Agency (see below).

The IAEA examined three areas bearing on our responsibility to future generations:

- Efforts required to reduce the probability of inadvertent human intrusion through information preservation, difficulty of access, and markers;
- Ethical and scientific consideration of the interplay of assessment uncertainties (which increase monotonically with the forecasting timescale) with concepts like discounting future events, the use of “expectation” values (probability times consequence), optimization of radiological protection in terms of the cost to achieve, and truncation of the time horizon at points where assessment uncertainties swamp meaningful current decision parameters;
- The question of how to implement a nuclear materials safeguards regime that will have no impact on the safety of the isolation barriers and impose no unreasonable burden on future generations.

It is not possible to briefly summarize the 42 pages of this IAEA “Principles” report, except to say it is a free-ranging discussion of these three issues with ample references to prior relevant work. The one central conclusion in the report, taken with due credit from an earlier study is the following:

> "The objective of radioactive waste management is to deal with radioactive waste in a manner that protects human health and the environment now and in the future **without imposing undue burdens on future generations"**

> (emphasis added).
>
> "The ethical principle for this is the premise that the generation that produces waste should bear the responsibility for managing it. The responsibility of the present generation includes developing the technology, operating the facilities and providing funds for the management of radioactive waste."

In a 1995 report, an IAEA Safety Series publication (IAEA 1995), perhaps the central operative paragraph states:

> "Consideration for future generations is of fundamental importance in the management of radioactive waste. This principle is based on the ethical consideration that the generations that receive the benefits of a practice should bear the responsibility to manage the resulting waste. Limited actions, however, may be passed to succeeding generations, for example, the continuation of institutional control, if needed, over a disposal facility."

This report goes on to deal with the full spectrum of safety requirements in terms of general principles to be applied to planning, siting, legal framework for regulation, monitoring, etc. It makes one very important observation about performance uncertainties and the protection of the biosphere:

> "While it is not possible to ensure total isolation of radioactive waste over extended time-scales, the intent is to achieve reasonable assurance that there will be no unacceptable impacts on human health. This is typically achieved by applying the multi-barrier approach in which both natural and engineered barriers are utilized."

More recent reports from the IAEA have confirmed the concepts above but have further tied our responsibilities to future generations to the concept of sustainable development. They take sharp issue with indefinite storage strategies, saying, for example, "perpetual storage of radioactive waste is not a sustainable practice and offers no solution for the future." **It was observed that perpetual storage does not meet the ethical precepts in the guiding international standards and principles for radioactive waste management** (IAEA 2007)

The Compromise For Retrievability

In recent years, disposal programs in many nations have given more consideration to retrievability of waste emplaced in a repository, as a contingency for the unexpected. In truth, this is more in response to a public preference than to an engineering need. Retrievability will be seen to exact some small cost in safety assurances and of course levies a burden on future generations to make decisions requiring knowledge and resources they may no longer possess.

Very recently, the IAEA published a report on retrievability questions related to radioactive waste disposal (IAEA 2009). The technical trade-off for retrievability is stated concisely in the report: "there is a potential prospect of an uneasy compromise between the technical requirements of the safety case and any prevailing socio-political pressures (for retrievability)."

The report summarizes the ethical issues related to the question of retrievability and how they had been explored by three nations. Briefly, Canada decided to maintain retrievability until "a future generation" decides to close the repository; France decided to design for providing retrievability for at least 100 years; and Sweden chose <u>both</u> to preclude the necessity of monitoring and maintenance and to "not unnecessarily impair" future attempts to retrieve the waste, monitor or repair the repository. That dual objective is available only because they chose crystalline bedrock for the geologic setting (their only practical choice) and also plan to employ a very expensive waste canister.

Extended retrievability was not emphasized in the early U.S. program. The current United States program started with a rudimentary screening of all potential rock types, in part so as to maintain geographic balance in the program and thus to approach an element of fairness (every region of the country being considered). This geographic balance was preserved and emphasized in provisions of the NWPA of 1982 (See Carter, 1987). Had retrievability been a primary goal then, salt rock formations might have scored lower in comparison with other host rocks. That would have been ironic given that the National Academy of Sciences had early expressed a particular confidence in salt as a host rock (National Research Council, 1957).

A primary advantage of salt rock is that over decades, rock creep under lithostatic pressure tends to close and seal mine openings (Minkley, et al, 2001). Waste retrieval would require re-excavation. Considering that the existence of the salt formation indicates an absence of moving groundwater, and that access shafts may connect to overlying groundwater, measures to retain openings and retrievability for long periods could compromise the potential for otherwise very effective waste isolation. Germany has emphasized salt as the primary host rock option and has studied the feasibility of re-excavation for waste retrieval.

At present, the Yucca Mountain design is intended to maintain retrievability for a minimum of 50 years after the start of waste emplacement and until the end of a confirmation period preceding closure. Yucca Mountain's volcanic Tuff is one of those host rocks that best accommodate retrievability.

3.2 NEA/OECD and HLW Disposal

The Nuclear Energy Agency (NEA) does not occupy the same political space as the IAEA. The IAEA, though legally and fiscally autonomous, operates under the aegis of the United Nations and, as such, has its focus more on treaties, conventions and other agreements, and on promoting safety standards for atomic energy development.

The NEA is a multinational agency dedicated to cooperative symposia and workshops for OECD member states, most of which are high-income representative democracies. Since its founding in 1958, it has sponsored a great many such meetings and has produced a very large body of literature on radioactive waste management. We shall focus primarily upon a sample of those reports bearing on intergenerational equity as a moral principle that energizes the member states to sustain their commitment to geologic disposal.

In meetings and conferences of experts and authorities from member nations, the assumptions, scientific findings, successes and vicissitudes of the various national programs are periodically examined. The objective of each of these meetings is to share lessons learned and to seek a collective wisdom on what makes sense for the future.

This process has not been completely understood by some social scientists who have increasingly become participants in the conversation over US policy in HLW disposal. Douglas Easterling and Howard Kunreuther (1995), in their otherwise commendable book, concluded as follows:

> "Even if it is possible to license and build a repository at Yucca Mountain, it may not necessarily be in the best interests of the country to proceed with this option. In particular, burying spent fuel underground may turn out to be an inappropriate solution to the waste dilemma. Although many scientists concluded during the 1970s and 1980s that geologic disposal was a safe and viable technology, doubts are now emerging. This is evident in the background document written for a 1994 OECD workshop on geologic disposal." The cited reference is NEA/RWM/DOC(94)1.

The "background" document they cite to support this gloomy assessment of the technical prospects for geologic disposal was intended only as challenging spur to the workshop participants. It was deliberately provocative (Pescatore 2010). Both the background document and the workshop proceedings are out of print and not widely available, but the conclusion of the Workshop deliberations is available as a collective opinion of the NEA Radioactive Waste Management Committee (NEA/OECD 1995). The most relevant findings of the Committee were:

> "Whilst the state-of-the-art in this field is relatively advanced and known,

diverging views are often expressed calling, from time to time, for a reappraisal of the proposed approaches and actions. As in many other areas, extensive international exchanges of views help in clarifying the issues involved and in formulating consensus positions which may assist national authorities in their search for appropriate solutions. …

"This report presents such a consensus position in the form of a Collective Opinion of the Radioactive Waste Management Committee (RWMC) of the OECD Nuclear Energy Agency. It addresses the strategy for the final disposal of long-lived radioactive wastes seen from an environmental and ethical perspective, including considerations of equity and fairness within and between generations. …

"After a careful review of the environmental and ethical issues, as presented later and discussed in detail in the proceedings of the NEA Workshop, the members of the NEA Radioactive Waste Management Committee:

- consider that the ethical principles of intergenerational and intragenerational equity must be taken into account in assessing the acceptability of strategies for the long-term management of radioactive wastes;
- **consider that from an ethical standpoint, including long-term safety considerations, our responsibilities to future generations are better discharged by a strategy of final disposal than by reliance on stores which require surveillance, bequeath long-term responsibilities of care, and may in due course be neglected by future societies whose structural stability should not be presumed** (emphasis added);
- note that, after consideration of the options for achieving the required degree of isolation of such wastes from the biosphere, geological disposal is currently the most favoured strategy;
- conclude that stepwise implementation of plans for geological disposal leaves open the possibility of adaptation, in the light of scientific progress and social acceptability, over several decades, and does not exclude the possibility that other options could be developed at a later stage."

These consensus judgments have held through the intervening years up to and including the most recent such collective opinion (NEA/OECD 2008a). It states, in part:

"**The overwhelming scientific consensus worldwide is that geological**

> **disposal is technically feasible**. (emphasis added) This is supported by the extensive experimental data accumulated for different geological formations and engineered materials from surface investigations, underground research facilities and demonstration equipment and facilities; by the current state of the art in modelling techniques; by the experience in operating underground repositories for other classes of waste; and by the advances in best practice for performing safety assessments of potential disposal systems.
>
> "There will always be some stake-holders that will not be fully convinced of the pertinence and safety of a specific geological disposal proposal. This is a reality in any societal decision process. Value and perception differences are real and must be respected, and there must be a continued dialogue to air these differences. In the end, important societal decisions have to be made, and the role of the regulatory system in determining whether a geologic disposal facility is sufficiently advanced and safe for implementation must be respected.
>
> "With the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, the Safety Standards of the International Atomic Energy Agency, and the recommendations of the International Commission on Radiological Protection there is now a common framework that guides national regulatory oversight and implementation of disposal.
>
> "International conventions and guidance under the aegis of expert bodies, such as the International Commission on Radiological Protection (ICRP), the IAEA and the NEA, provide a suitable framework for applying a stepwise approach in decision making and protecting future generations without imposing undue burdens on them.
>
> "Reversibility and retrievability are considered by some countries as being important parts of the waste management strategy. Reversibility implies a disposal programme that is implemented in stages and that keeps the options and choices open at each stage, and provides the capacity to manage the repository with flexibility over time under specified conditions. Retrievability is the possibility to reverse the step of waste emplacement. There is general recognition that it is important to clarify the meaning and role of reversibility and retrievability for each country, and that provision of reversibility and retrievability must not jeopardize long-term safety."

Though the NEA reports most often address our obligations to "future generations," many reports refer to the phrase "intergenerational equity" in discussing ethical dimensions of the waste disposal problem. For example, the

Proceedings of a 2007 NEA Conference on the safety of geologic disposal (NEA/OECD 2008b) concisely relates safety to this concept:

> "The problem of dealing with long-lived radioactive waste forces us to think seriously about exotic concepts such as intergenerational equity across millennia, responsibility towards non-human biota and the importance of preserving a sound environment as a basis for sustainable life on earth. The stepwise development of the disposal facilities with the possibility of independent reviews and public involvement at each step will allow us to adjust and improve the projects as [research] developments unfold."

By 2006, several member countries had responded to public concerns with consideration of long-term interim storage regimes as a precursor of sorts to permanent disposal. The attraction is the feature of reversibility, in case of some untoward development, and a slowed schedule that allows for a public dialog to proceed at its natural pace. With storage periods of 100 years, there can be a significant reduction in the heat load imposed by spent reactor fuel and thus a reduced uncertainty in geologic response to disposal. However, the NEA expressed the following reservation related to intergenerational equity in NEA/OECD 2006.

> "Extended storage could be chosen for some kind of waste or for all waste, as an element of flexibility in a global fuel cycle. Providing a large cooling time brings some clear benefit for HLW. And, finally, the society may bet on important scientific improvements which would modify the radioactive waste landscape. It should be emphasized that any decision on LTIS (Long-Term Interim Storage) requires a strong and conscious commitment by the society as such a facility must be always watched and maintained rigorously until it is emptied. **Special attention must be provided to avoid that LTIS transforms itself surreptitiously into bad disposal. The logic on intergenerational responsibility requires that some financial provision be made for long-term maintenance and operation.**"

This is a key statement, but by no means covers all of the factors bearing on a decision to extend the role of storage beyond logistical purposes. Readers interested in a more complete analysis are directed to the cited NEA report. There are substantial ethical, logistical and safety complexities attached to the storage implementation options (e.g., regional vs. centralized, time horizon, above or below ground).

It is possible to merge LTIS with a disposal facility by maintaining retrievability in a geologic repository for an extended period of surveillance. Hard rock settings and dry environments above the water table allow this option to be implemented with reduced uncertainties to long-term safety. For example, Yucca Mountain could be kept in a surveillance mode for two or three hundred years, while a salt rock mine with heat-producing waste possibly could not (due to creep closure tendency). The Swedish authorities are taking this approach, with a demonstration facility being extended to a full repository if no problems emerge during a decade or more of close surveillance. Retrievability would be maintained until a future generation decided to permanently seal the repository.

3.3 European Commission

The European Commission has periodically conducted surveys of public opinion in the EU and reported the results under the title "Eurobarometer." In 1998, 2002, 2005 and 2008, they performed special surveys of opinions about nuclear power and nuclear waste. The 2008 report (European Commission, 2008) reported that

> "More than nine in ten (93%) Europeans on average see an urgent need to finding a solution to the problem now, rather than leaving it unsolved for later generations."

3.4 Sweden's Experience in HLW Disposal

Kunreuther, et al (1996b), in a comparative study of hazardous facility siting in the US and EU, describe the selected projects on a two-dimensional scale measuring the degree to which the pertinent information and decision making are open to the public and the degree to which the decision-making authority is possessed by local communities (veto rights) or by the facility developer (likely an organ of national or county government). The Swedish approach exhibits great openness and somewhat centralized final decision authority.

In a society not always enthusiastic about nuclear power, among a people who experienced significant fallout from the Chernobyl incident, their nuclear waste disposal program has nonetheless had notable success. It is worth a brief look at what might be the contributing factors.

The responsibility for disposal of Swedish spent nuclear fuel (SNF) is assigned to a private consortium, the Swedish Nuclear Fuel and Waste Management Company (SKB) that is jointly owned by the nuclear power plant operating companies. SKB is thus discharging a legal responsibility (implementing final disposal) imposed by Swedish law on the nuclear utilities as a condition of continued reactor operations.

SKB must consult with the Swedish Radiation Safety Authority (SSM) [formerly the Nuclear Power Inspectorate (SKI) and the Radiation Protection Institute (SSI)] throughout its planning, R&D, storage and disposal activities. Typically, organs of the government must endorse the SKB R&D plans and can change the waste disposal fee charged to the utilities so as to cover the scope of work. SSM and an Environmental Court will ultimately certify regulatory compliance of any proposed disposal facility and design. SSM works under the Ministry of Environment, as does an independent advisory committee named the Swedish National Council for Nuclear Waste (KASAM). KASAM is comprised largely of university academics representing physical and social sciences and engineering.

KASAM performs a role similar to the Nuclear Waste Technical Review Board (NWTRB) created by the U.S. Congress in 1987, and the various committees of the National Research Council that have advised the DOE over the years (notably, the Nuclear and Radiation Studies Board, the Board on Earth Sciences and Resources, and the Board on Radioactive Waste Management). However, KASAM has a much larger public outreach function. It arranges hearings and seminars and has published a number of polished full-color brochures and reports covering R&D needs, ethical dimensions, site selection and evaluation (procedures and technique), risk assessment and long-term safety, and public opinion. All of these reports were (and are still) printed in profusion and widely distributed to the Swedish public for free.

Remembering that KASAM is a panel of independent academics, it is easy to imagine that their public outreach was far more credible than would have been the case with the nuclear utilities or the private waste management consortium (SKB). Because of its higher public profile, and the fact that it's findings and recommendations raise very public expectations for SKB spent fuel management, KASAM has spoken with more social impact than have the U.S. advisory panels.

The end result is that SKB has generally performed its R&D and conducted siting studies <u>after</u> a calm discussion of relevant issues has taken place in the public space. The Swedish public has seen its intuitive concerns and topics like geologic uncertainty, waste form, interim storage and ethical dimensions all deliberated by serious people who have no conceivable conflict of interest.

The U.S. National Research Council assembles comparable committees of experts to advise our national waste management program, but it has not pursued a similar degree of public outreach. For example, the National Academies Press, which distributes National Research Council reports, only went online in 1993. They first offered printed copies of reports for sale from the web site in 1994. Open (free of cost) searchable report text was first made available in 1998 (Dossinger 2010). The U.S. repository program considered and often heeded the NRC guidance, but then made the key choices of technology and siting <u>before</u> there was open public availability of NRC findings and recommendations. There have been occasional complaints, as well, by stakeholders who felt shut out of the NRC deliberations, one example being states and tribes objecting to a lack of (effective) participation throughout the NRC review of the decision-aiding methodology that informed the

DOE selection of the three final candidate sites for the first repository (see GAO 1987, page 54).

The NWTRB makes a genuine effort to freely distribute their reports, but their statutory agenda is strictly technological and never reaches many of the ethical and socio-economic issues of first importance to the public. Also, the NWTRB was not created until 1987, in the same Act of Congress that incited such heavy resentment in Nevada. It was not available in the formative stages of the U.S. program when it might have had more impact on the credibility of the mission and approaches.

In contrast to the Swedish “academic” outreach approach, DOE, being both the implementing agency and the inheritor of all the waste management shortcomings of the AEC period, must push against a bow-wave of distrust when it is out front in the interactions with the media and general public.

Sweden currently has 10 operating power reactors providing just over 40 percent of Sweden’s electricity demand, down from 12 reactors in 1998. They have up-rated several of their remaining power stations to higher power levels needed to meet demand. (see World Nuclear Association web site for this data). Swedish politicians and the public have been ambivalent about nuclear power. In a 1980 voter referendum, the public favored phase-out of Sweden’s dependence on nuclear power after the existing units reached end of life, but recently majority support has formed around further nuclear expansion to support climate change goals (Macalister 2009).

Again comparing with the U.S. experience, many of Sweden’s public deliberations and key decisions on disposal occurred during a period following a moratorium on further expansion of nuclear power. This relieved the public dialog on waste disposal from opposition rooted in ideological resistance to nuclear power.

SKB has had an interim storage facility in operation since 1985 near Oskarshamn. It is a pool storage facility located in a mined cavern 25 meters deep in basement crystalline rock. A site at Forsmark, in the municipality of Östhammar, was selected for permanent disposal of spent fuel in June 2009. A license application to construct the repository is expected in 2010. The siting process began with feasibility studies in eight municipalities, after which Östhammar and Oskarshamn volunteered to be candidate finalists. In addition to on-site field geological studies, the site selection was supported by data developed in the Äspö hard rock laboratory opened in the 1990’s.

As the guiding light of the Swedish program, the KASAM findings over recent years are worth noting. Following are selected technical findings from the most recent review of the SKB R&D program (KASAM 2008).

> "With present-day knowledge of possible alternatives to the KBS-3 method [a specific design concept for disposal in mined caverns approximately 500 meters deep into crystalline bedrock], there are strong reasons to continue current research and development work focusing on direct disposal in accordance with the KBS-3 method. **In KASAM's view, it is not acceptable to postpone the Swedish final repository programme with reference to alternative methods as possible technologies.** (emphasis added).
>
> "The Council concurs with SKB's assessment that transmutation presumes that Sweden makes a much more long-term commitment to nuclear energy than is currently the case. However, the Council also notes that even this technology leads to long-lived waste, although in smaller volumes.
>
> "The Council's conclusion after the hearing on deep boreholes is that there does not appear to be any available technology (in the sense of the Environmental Code) for disposal in deep boreholes, and that such technology cannot be expected to become available within the timespan of the planned decision process. However, both drilling technology and sensor technology have been developed during the past 10–15 years. The Council therefore believes that very good reasons exist for SKB to clearly present and explain its standpoints regarding the deep borehole concept both in RD&D Programme 2007 and in the upcoming applications for permits … to build a final repository
>
> "The external role of the safety assessment is to systematically coordinate information from all relevant technical and scientific areas in order to show that the proposed final repository system meets all safety requirements imposed by the regulatory authorities (which must in turn reflect societal values). … The Swedish National Council for Nuclear Waste would also like to emphasize the internal role of safety assessment within SKB as a tool for both following up repository safety during construction and operation and providing guidelines for technology development and research."

It is clear that Sweden has sustained its commitment to the geologic disposal option and sees little to no advantage in often-mentioned alternatives. Nonetheless, they advise SKB to be prepared to give a firm discussion of alternatives when they file the environmental impact assessment that must accompany their construction license application. The US program crossed that bridge when it developed the EIS on Management of Commercially Generated Radioactive Waste (US DOE 1980) on the schedule required by US law (NEPA).

KASAM has also expressed a number of findings related to ethical issues, specifically including intergenerational equity. Here are some selected examples instructive to our current U.S. dilemma (KASAM 2007b).

> "It was against this background [the necessity to make decisions in the face of uncertainty] that the so-called KASAM principle was formulated: "A final repository should be constructed so that it makes inspection and controls unnecessary, without making inspection and controls impossible. **In other words, our generation should not place the entire responsibility for the final repository on future generations, but neither should we deprive future generations of the option of assuming responsibility**. … The final repository should be designed with the aim of achieving the highest possible safety from the start, while at the same time allowing for change and improvement.
>
> "Unless it is kept effectively isolated from the biosphere, Sweden's spent nuclear fuel could otherwise cause harm to humans and other life forms – both those living today and those living several hundred thousand years from now. Awareness of the severity of the problem implies that it is necessary to achieve a workable final repository solution as soon as possible. The residual radiation and its toxicity for the next several hundred thousand years is a measure of the challenge posed by the nuclear waste issue to our generation. Ultimately it is an ethical and a moral challenge.
>
> "If we accept the idea of sustainable development, we also accept that we have a moral obligation towards future human generations. Resources and burdens ought to be distributed fairly between current and future generations.
>
> "The dominant form of consequential ethics is utilitarianism, and this is well suited for probability analysis. [Note: utilitarianism can be defined in different ways, but one definition would have an action be morally right if it will lead to the greatest good for the greatest number.] The treatment of risk and uncertainty in economics has utilitarianism as its philosophical basis. The formalized risk assessment is based almost exclusively on utilitarian models. … The utilitarian theory appears to be very relevant for providing an ethical interpretation of the Swedish regulatory framework surrounding final disposal of spent nuclear fuel. The fundamental issue has to do with minimizing the harmful effects of the nuclear waste among everyone affected by the action, including future generations. The risk and safety assessment provides us with the answer to the ethical challenge of nuclear waste as well.
>
> "This principle of producer responsibility (also called the "polluter pays

> principle") has been of fundamental importance for the management of spent nuclear fuel in Sweden. … By "polluter" is mainly meant here the nuclear power producers, but the principle can also be interpreted as applying to those who have used the electricity, i.e. the electricity consumer. **This means that we in Sweden bear a common responsibility for our country's radioactive waste. It must not be passed on to future generations, but rather be managed and disposed of today.** We can call this the responsibility principle.
>
> "Making the decision process and basis for decision for nuclear waste management transparent [is of fundamental importance]. It has to do with facts (is this true?), legitimacy (is this fair?) and authenticity (are you being honest & what are your values?). [This] entails giving the participants insight and an opportunity to form an opinion regarding the truthfulness and relevance of the arguments and the actors' authenticity. This is done by [our] subjecting the actors to thorough interrogation from various angles and clarifying the values behind the arguments."

Finally, the Swedish authorities have recognized the necessity for the Swedish people to step beyond the usual individualistic ethic to a more communitarian civic responsibility (KASAM 1988):

> "Western ethics have been traditionally dominated by rules for the actions of the individual. Furthermore, these rules have revolved around people's personal interests and needs. However, now [with nuclear waste] that the horizons of responsibility are broadening to include the consequences of our actions for the condition of all life far into the future, the common responsibility which we bear collectively must occupy stage center as it never has before."

It is this author's opinion that such a shift is much easier for Swedish society than, for example, for Americans simply because they start from a more communitarian social outlook from the outset. Social cohesion is sustained by a much more homogeneous demographic (CIA World Factbook). They are not steeped in a tradition of suspicion of government, disdain for public service and resentment of intellectual elites (e.g., scientists and senior administrators). They have a much more generous social safety net, including universal health care, unemployment compensation, disability income and other interventional social services (OECD 2009). These provisions inspire at least some confidence that anyone suffering from adverse fates (like unemployment) will be made whole. In comparison, American citizens have become accustomed to the assumption that "you're on your own." When unemployment can lead to loss of medical care, bankruptcy and foreclosure, you are rationally less tolerant of perceived economic and health threats from a spent fuel repository, or any other potentially stigmatic presence, for that matter.

Sweden had little trouble proceeding with repository feasibility studies in eight municipalities. During the course of studies, three municipalities decided against being included in further consideration and were thereafter dropped, one site was disqualified, and of the remaining four, two were selected as finalists. By comparison, the government of every state considered by the U.S. Department of Energy, at some point in the siting process, vigorously opposed and objected to their being considered (Carter 1987, pp. 145-193, and Easterling and Kunreuther 1995, p. 40 and 56).

3.5 Dispute About Implications and Obligations of Intergenerational Equity

It would be remiss not to recognize that intergenerational equity is a two-edged sword, so to speak. The essence of the dispute is whether it is more equitable to apply our best available technology to sequestering spent nuclear fuel so as not to impose the burden on future generations, or rather to maintain the SNF in secure monitored retrievable storage so as to give those future generations the option to do with it what seems best to them. One of the foremost proponents of the latter view in favor of LTIS is Kristin Shrader-Frechette, Professor of Biological Sciences and Philosophy at the University of Notre Dame (Indiana). Below is a particularly condensed expression of her views on the subject, taken from (Shrader-Frechette 1993).

> "Still other proponents of a permanent repository argue that we should not pursue NMRS [Negotiated Monitored Retrievable Storage] sites because leaving the HLW in temporary facilities would burden future generations, forcing them to deal with a problem that we have imposed on them. Permanent disposal, however, might free them from this burden. Indeed, this is the official position of the Sierra Club, a conservation organization that opposes NMRS and supports permanent disposal.
>
> "In response to the objection about burdening future persons, one important reply is that the objection begs the question. If the issue is whether or not NMRS burdens the future persons more than permanent disposal does, then to argue that NMRS poses a greater future burden is to assume that permanent disposal presents less of a burden. However, this conclusion is assumed because for permanent disposal to present less of a burden, we would need to have a reasonable guarantee that the disposal was safe, and that the canisters and site geology provided protection for many centuries. Because we do not have this reasonable guarantee, and because the permanent repository will not be monitored forever, there are strong grounds for believing that it could present a great burden to future persons. Also, if

> "the devil you don't know is worse than the devil you know," then unmonitored permanent facilities could be a worse burden than monitored temporary facilities. Otherwise, one would be committed to the problematic assumption that what you don't know couldn't hurt you. Indeed, what you don't know is probably more likely to hurt you. Hence, the greater future burden may lie with permanent disposal. Moreover, provided that NMRS facilities are associated with a permanent public trust to defray costs of monitoring and accidents, then the burden on future persons is likely to be minimized, or at least minimized more than a burden for which there is no permanent monitoring, no complete retrievability, no complete compensation, and no complete trust funds available. Also, because our NMRS proposal provides for retrievability and monitoring of the waste, future generations could lessen their burden through scientific developments or through a plan for ultimate geological disposal. If one pursues the permanent repository option now, however, then that decision will be, practically speaking, irreversible. Hence, NMRS repositories reduce the irreversibility burden."

The Swedish National Council for Nuclear Waste published a particularly clear statement of the rationale supporting permanent geologic disposal. Inadvertently, it provides an exact rejoinder to the view of Prof. Shrader-Frechette. The Swedish argument is the following (KASAM 2007b):

> "Let us assume that it is probable that better technology in the future could make a final repository safer than the best technology available today. Is this sufficient reason to abandon the responsibility principle and shift the burden of finding a solution to future generations? This is questionable, since it is possible that we already have a sufficiently safe solution for final disposal today and a future solution would only marginally improve safety for future generations. In order to justify setting aside the responsibility principle we must assume that we do not have sufficiently good technology today to build a final repository. But this remains to be determined when SKB has submitted its application for a permit to build a final repository for spent nuclear fuel in 2009. [This is exactly the situation now in the U.S., where the Yucca Mountain license application is under review by the U.S. Nuclear Regulatory Commission.]
>
> "Furthermore, it is not at all certain that we will have a better technology hundreds of years from now. Instead of progressing, society may regress. The country may be struggling with serious economic, social or medical problems. The competence in the nuclear waste field currently possessed by regulatory authorities, nuclear power utilities, SKB, universities and consultants will dissipate. If nuclear power has moreover been phased out at

the same time and the waste management work has been put on hold, the field will lose its interest and fail to attract new recruits. That will put us in the worst of all worlds: a society in crisis without the resources to dispose of the hazardous waste.

"Enthusiasm, broad expertise and detailed knowledge exist now. To risk wasting these resources is not a good alternative."

4.0 Background on Intergenerational Equity

> ***Note to the reader: this section is about the origins of the concept of intergenerational equity in modern thought, and how it is connected to the values of justice, fairness and responsibility. Connections to "sustainable development" as that phrase has been embedded in international environmental law are also considered. One of the major issues that attach to intergenerational equity is the rate of present-worth discounting (if any) that should apply to future benefits and costs, when considering present-day investments. None of these topics are immediately germane to the geologic disposal questions of today. This section could thus easily be set aside for a later reading. The reader may therefore wish to proceed directly to the Conclusions.***

4.1 John Rawls and Intergenerational Justice

John Rawls, in his Theory of Justice, first developed an ethical framework for obligations to future generations (Rawls, 1971). He said:

> "Each generation must not only preserve the gains of culture and civilization, and maintain intact those just institutions that have been established, but it must also put aside in each period of time a suitable amount of real capital accumulation. This saving may take various forms from net investment in machinery and other means of production to investment in learning and education."

Rawls arrived at this statement from a philosophical framework that is called distributive justice, but where the distribution is not lateral among current members of society, but forward in time to our progeny. It is a statement of his notion of a "just savings rate" and is just about as far as he could reach with respect to obligations to individuals yet unborn. He was trying to "derive" a logic of justice, starting with the fewest assumptions. Rawls states that rules of social justice represent the negotiated terms of cooperation for mutual advantage, given the "circumstances of justice" (available capacities and scarcities, the structure of the society). Fair rules and procedures will result if the participants enter the negotiations with a kind of selective amnesia, where they know the issues and properties of their society but are unaware of their personal status (am I a tenant or landlord, manager or worker, King or shoemaker?). He called this imagined state a "veil of ignorance." Rawls thus reached the notion of "justice as fairness." In this social contract approach to justice, it is hard to envisage the participation of unborn descendants in the negotiation, and it is harder still to surmise either their circumstances or their aspirations.

Rawls' restricted formulation of intergenerational justice was not uncontroversial (Barry, 1989 and Nozick, 1974). But James Tobin, a Noble laureate economist (in 1981) saw similar obligations to the future arising in the management of endowments, saying (Tobin 1974):

> "The trustees of endowed institutions are the guardians of the future against the claims of the present. Their task in managing the endowment is to preserve equity among generations."

This boiled down to the principle that spending from an endowment on current qualified beneficiaries should be constrained so as not to deprive future qualified beneficiaries their equitable portion.

4.2 The Brundtland Commission and the United Nations Stockholm Declaration

Beyond those early economic formulations of intergenerational equity, the concept has had increasing presence in environmental policy and international agreements. Though not using the term explicitly, the Declaration of the United Nations Conference on the Human Environment, held in Stockholm in June 1972 (United Nations 1973) had the following to say about obligations to future generations:

> "To defend and improve the human environment for present and future generations has become an imperative goal for mankind - a goal to be pursued together with, and in harmony with, the established and fundamental goals of peace and of worldwide economic and social development."

This is not a trivial statement. It puts environmental protection on a par with the original UN purpose of promoting and maintaining international peace and security (see Article 1, Chapter 1, United Nations Charter).

The World Commission on Environment and Development, appointed by the UN General Assembly and chaired by Gro Harlem Brundtland, former Prime Minister of Norway, looked extensively at the concept of sustainable development, the complex of issues it was intended to address, and proposed legal principles to support sustainable development (United Nations 1987). Most fundamentally, the Brundtland Commission, as it came to be called, put forth a definition of "sustainable development" to be adopted as a UN objective. That definition was:

> "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:
>
> 1. the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and

2. the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs.

> Thus the goals of economic and social development must be defined in terms of sustainability in all countries - developed or developing, market-oriented or centrally planned."

4.3 Edith Brown Weiss on Law and Intergenerational Equity

One of the most-cited authorities on International Economic and Environmental Law is Edith Brown Weiss, Professor of International Law at Georgetown University Law Center. She has held posts at the US EPA, United Nations, the World Bank, and various committees of the US National Research Council. In 1992, she edited a volume anticipating the transnational legal issues presented by the arrival of global environmental challenges such as ozone depletion and climate change, and wrote a chapter on intergenerational equity (Weiss, 1992).

Ozone depletion and greenhouse gasses present problems of impacts over large time horizons, earth science modeling, risk assessment, and decisions in the face of uncertainty. We have seen that these features are shared with radioactive waste disposal. The cited book was a linchpin reference for future policies of sustainable development, the precautionary principle and the responsibilities of state actors.

As regards, intergenerational equity, Weiss described it as a component in the legal framework for meeting global environmental change. First reviewing the legal history of intertemporal law, she states the following legal summary:

> "Concern for justice to future generations regarding the natural environment first emerged as a major concern in the preparatory meetings for the 1972 Stockholm Conference on the Human Environment. The concept of protecting the natural environment for future generations was explicitly incorporated into the language of three treaties negotiated more or less contemporaneously with the Stockholm Declaration: the 1972 London Ocean Dumping Convention, the 1973 Convention on International Trade in Endangered Species, and the 1972 Convention Concerning the Protection of the World Cultural and Natural Heritage."

Weiss analyses intergenerational equity, starting at the polar positions of attitude about our relationship to the future and then looking at the relevant implications of the world's various religious and secular traditions.

> "The first [polar position] is the preservationist model, in which the present generation does not destroy or deplete resources or significantly alter anything; rather it saves resources for future generations and preserves the

> same level of quality in all aspects of the environment. This preservationist model has deep roots in the original natural-flow theory of English water law, in which riparians could use stream water so long as their use did not impair in any way the quantity or quality of water for those downstream. The preservationist model, if carried to its extreme in saving unspoiled ecosystems, would promote the status quo. It is only consistent with a subsistence economy, not with an industrialized world … future generations benefit at the expense of earlier generations.
>
> "The other extreme can be termed the 'opulence' model in which the present generation consumes all that it wants today and generates as much wealth as it can, either because there is no certainty that future generations will exist or because maximizing consumption today is the best way to maximize wealth for future generations. … Further under this model, the present generation may trigger irreversible changes in the global climate system that will affect habitability in parts of the world.
>
> "A variant of the opulence model is the technology model, in which we do not need to be concerned about the environment for future generations, because technological innovation will enable us to introduce infinite resource substitution. While technology will undoubtedly enable us to develop some substitutes for certain resources and to use resources more efficiently, it is by no means assured that it will suffice or will make the robustness of the planet irrelevant."

Following this analysis, she arrives at her proposed definition of intergenerational equity, as a basis for development of future environmental law:

> "Three principles form the basis of intergenerational equity. First, each generation should be required to conserve the diversity of the natural and cultural resource base, so that it does not unduly restrict the options available to future generations in solving their problems and satisfying their own values, and should also be entitled to diversity comparable to that enjoyed by previous generations. This principle is called 'conservation of options.'
>
> Second, each generation should be required to maintain the quality of the planet so that it is passed on in no worse condition than that in which it was received, and should also be entitled to planetary quality comparable to that enjoyed by previous generations. This is the principle of 'conservation of quality.'
>
> Third, each generation should provide its members with equitable rights of access to the legacy of past generations and should conserve this access for future generations. This is the principle of 'conservation of access.'

> “The proposed principles recognize the right of each generation to use the Earth's resources for its own benefit, but constrain the actions of the present generation in doing so. Within these constraints they do not dictate how each generation should manage its resources. They do not require that the present generation predict the preferences of future generations, which would be difficult if not impossible. Rather, they try to ensure a reasonably secure and flexible natural resource base for future generations that they can use to satisfy their own values and preferences. They are generally shared by different cultural traditions and are generally acceptable to different economic and political systems.
>
> “The principle of conserving quality is consistent with environmentally sustainable growth. It does not mean that the environment must remain unchanged, which would be inconsistent in any event with conserving the present generation's access to the benefits of the planet. In determining whether one generation is conserving quality, trade-offs are inevitable. For example, we may exhaust more reserves of a natural resource and cause modest levels of pollution, but pass on a higher level of income, capital, and knowledge.
>
> “The principles of options (diversity), quality, and access form the basis of a set of intergenerational obligations and rights, or planetary rights and obligations that are held by each generation. These rights and obligations derive from each generation's position as part of the intertemporal entity of human society. Planetary intergenerational rights and obligations are integrally linked; the rights are always associated with obligations. They represent in the first instance a moral protection of interests, which must be transformed into legal rights and obligations.
>
> “Intergenerational rights of necessity inhere in all generations, whether these be immediately successive generations or ones more distant. There is no theoretical basis for limiting such rights to immediately successive generations. If we were to do so, we would often provide little or no protection to more distant future generations. Nuclear and hazardous waste disposal, the loss of biological diversity, and ozone depletion, for example, have significant effects on the natural heritage of more distant generations.”

Contemporary with Prof. Weiss’ analysis above, the United Nations held a Conference in Rio de Janeiro on Environment and Development (United Nations 1993). The Annex to the Conference report contained the so-called Rio Declaration that was immediately adopted by the UN General Assembly. It built upon the Stockholm Declaration of 1972, mentioned above, laid out a vision of sustainable development, and included the following principles of interest here:

> Principle 3 - The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations.
>
> Principle 13 - States shall develop national law, regarding liability and compensation for the victims of pollution and other environmental damage.

The Rio Conference Report also included an implementation guide called "Agenda 21" and a non-binding statement of principles on forest management, both of which were also adopted by the UN General Assembly.

4.4 Can One Do Present-Worth Discounting of Future Mortality?

Everyone who has done investment analysis will be familiar with the practice of applying present-worth discounting to future revenue streams from a present-day investment expense. The rate of discounting that leads to a net cumulative present value of zero for the cash flows is called the internal rate of return.

Drawing an analogy, some have suggested that, when considering environmental regulation, future benefits should be discounted by a social discount rate. There is less disagreement about discounting when the future regulatory benefit is economic, say in preserving productive fisheries. Disagreement is more spirited when the future benefit is reduced mortality and disease. Is a life in the distant future worth less than a life today?

The question is crucial to the concepts of intergenerational equity and sustainable development. With respect to radioactive waste disposal, the trade-off parameters are money spent now and the marginal reduction in risk to future generations.

A great deal of ink has been expended on this subject, with a paper in 1995 by Nobel laureate economist Kenneth Arrow being most specifically addressed to future economic benefits. He argues that a discount rate of zero would result in an infinite utility in the benefits to an infinite number of future generations; therefore unlimited sacrifice by current generations would be justified. But according to the principle of universalizability (meaning, impartiality), a disinterested spectator would say that the moral position would treat all generations alike. A zero discount rate would sacrifice utterly the quality of life in the present because of the payoffs in the future. After some mathematics, Arrow concludes that a reasonable social discount rate would be between 3 and 4 percent (Arrow, 1995).

There is a distinction drawn between discounting future benefits over the life of living individuals and between living and unborn individuals, even if the time period in question is the same. Tyler Cowen (2001) has the following to say:

> "Time preference is part of the standard arsenal of arguments for discounting within a single life. Most individuals prefer to receive benefits

> sooner rather later. This claim has been prominent since the classical economists, such as Adam Smith. … Time preference within a life, however, cannot be extrapolated directly to time preference across different lives.
>
> "Consider a policy that would provide a benefit, forty years hence, for persons (some may wish to call them "future persons" or "prospective persons") who have not yet been born. Before these persons have been born, they are not waiting for the benefit to arrive and do not suffer abstinence. In other words, people ("future people") have no well-defined preference ranking over time periods before they are born. For this reason, pure time preference, taken alone, does not justify positive discounting for the entire forty years.
>
> "The passage of time before our births does not involve waiting or preference in the traditional fashion. It makes sense to claim that an individual would rather have an ice cream cone today than tomorrow. [It makes less sense to claim that we are worse off than a Medieval artisan because we have had to wait hundreds of years to appreciate his art.]
>
> "Critics of discounting are correct in the counterexamples they raise. We should not apply discounting of this kind to loss of human life, to environmental catastrophes, or to significant changes in human health. For most of the intergenerational policy issues that are hotly debated, this argument for positive intergenerational discounting is of very limited value.
>
> "Given these findings, most instances of positive intergenerational discounting should be interpreted as a form of interpersonal utility comparison between generations. This does not suggest that a zero rate is necessarily correct, but does indicate that **the choice of discount rate typically falls into the realm of ethics, and requires more normative presuppositions than are found in the standard body of ordinal welfare economics.**" (emphasis added).

Looking instead at the application of future discounting to the prospects of lives lost, Sunstein and Rowell (2005) frame the problem as follows:

> "Suppose that a proposed regulation will not produce benefits for many years; suppose too that an agency is asked to engage in some form of cost-benefit analysis before it proceeds with the regulation. Costs will be discounted, on the theory that a dollar today is worth less than a dollar in twenty years. But what should the agency do about future benefits, such as improved health or averted deaths? Should these too be "discounted," or should a death in 2025 be treated the same as a death today?
>
> "In terms of ultimate outcomes, the choice matters a great deal. If an agency

> chooses not to discount, the benefits calculation will shift dramatically from what it would be if the agency chose a discount rate of, for example, 10%. If a human life is valued at $8 million, and no discount rate is applied, a life saved 100 years from now is worth the same expenditure as a life saved now: $8 million. But at a discount rate of 10%, the same life would justify a modern expenditure of only $581. For regulation whose effects would be felt centuries from now, any reasonable discount rate will reduce apparently substantial benefits to close to nothing.
>
> "Economists tend to believe that the argument for discounting is obvious, though the consensus has started to unravel in the last decade. Philosophers and lawyers are often skeptical about discounting. Philosophers have raised serious doubts about the idea that a future death or illness should be discounted in the same way as money. Lawyers as well have questioned that idea, suggesting that it depends on contentious empirical or normative assumptions.
>
> "Ackerman and Heinzerling (2002) object that the choice implicit in discounting is between preventing harms to the current generation and preventing similar harms to future generations. Seen in this way, discounting looks like a fancy justification for foisting our problems off onto the people who come after us. They emphasize that with a discount rate of five percent, for example, the death of a billion people 500 years from now becomes less serious than the death of one person today – an evidently implausible conclusion.
>
> "On the other hand, it has also been argued that a failure to discount the monetized equivalent of regulatory benefits would lead to less regulation, not more. The reason is that if regulators are indifferent as between lives saved now and lives saved in the future, but discount costs at some positive rate, then it makes sense for them to delay life-saving expenditures indefinitely, simply because the cost-benefit ratio will (always) be better in the future."

Several theorists remind us that once one has monetized the risk of mortality, as regulators around the world have done, at least implicitly, present-worth discounting is being applied to the money equivalent of a statistical death and not to the death itself. Even assuming that our descendents 100 years hence would equally value a statistical life (current U.S. value is between 6 and 8 million dollars), have we done our duty by investing only the requisite $400,000 per statistical life put at risk (with 3 percent annual discounting) in the long-term safety of our project? Returning to Sunstein and Rowell, they say:

> "Critics are correct to say that discounting might contribute to serious

> problems of intergenerational equity. The reason is that with discounting, a cost-benefit analysis can lead the current generation to impose extremely high costs on future generations, and such costs might be imposed without providing compensating benefits to the losers -- leading to a net welfare loss, a serious distributional problem, or both.
>
> "It is possible, of course, that the current generation will effectively "pay off" the future generation, making it more than worthwhile for it to bear those costs; the problem of intergenerational equity would be resolved if future generations are in fact compensated because (for example) adequate sums of money have been invested for their eventual benefit. And the course of human history, with astounding improvements in wealth, health, and longevity, makes it plausible to suggest that something like this does happen over time. But there is no assurance that it will continue to occur, in general or for particular risks.
>
> "It is not at all clear, however, that a refusal to discount is the best way of reducing those risks. On the contrary, any such refusal might well harm members of future generations. Our submission is that if cost-benefit analysis with discounting imposes a serious loss on members of future generations, the current generation fulfills its obligations not by failing to discount, but by providing compensation for that loss."

Sunstein and Rowell then argue that the moral/ethical thing to do would be for the current generation to set up an endowment fund for future generations that compensates them for the statistical risk imposed upon them. If we fail to do this, they say, we have negligently committed a kind of tort on our descendents. This seems a reasonable intuitive conclusion, and their analysis usefully summarizes the issues in dispute. Nonetheless, papers continue to proliferate on this topic, from economists, legal scholars and philosophers, so there is no settled truth here.

5.0 Conclusions

At this time, the Yucca Mountain project has been stopped, and U.S. policy on commercial spent fuel awaits the promised review of “alternatives” by a Blue Ribbon Commission. That this should happen just after the application to the Nuclear Regulatory Commission for a safety review and license to construct makes clear that the decision was not driven by scientific finding, or lack thereof. The only competent authority to make that finding is the US NRC, which still has the license application and supporting data under review.

No, this decision was made to honor a campaign promise made by the current President and by his Presidential Primary opponent during the contest for Nevada Democratic Party voters. It was a political decision, flat out, extracted by Nevada Democrats as a condition of their support. Clearly, this is a regrettable waste: of money, of expert talent invested over many years and, depending upon what we do now, a subversion of our ethical responsibility to future generations.

It is regrettable, but is it unexpected that elected officials will respond to an overwhelming voter demand? Nevada resident surveys showed 80 percent opposition to Yucca Mountain project (Flynn, et al, 1991 and Slovic, et al 1991). This may be just another inefficiency of Democracy, albeit a spectacular one.

Still, other equally democratic countries like Canada, Sweden, Finland, France, Belgium, and Germany continue to pursue geologic disposal, despite occasional setbacks. Serious public concerns and amplified perceptions of risk occur in those countries also. But they are not talking vaguely about other options. None have developed a complete and cogent safety case and submitted it to licensing authorities. None have gone so far as the United States and then proposed to abandon the effort. Driven by the moral imperative of intergenerational equity, they stay the course toward geological disposal however they may have to set the sails in shifting winds.

It is particularly puzzling that DOE Secretary Chu would, as recently announced, withdraw the DOE license application now before the Nuclear Regulatory Commission. Withdrawing the application poisons the scientific process of independent peer review. Now is the time that the particulars of the earth science data and analytical processes and assumptions are fresh. The scientists and engineers that developed the safety case will have soon dispersed to other employers and projects. They will have other commitments and will begin to forget strands of the web of argument for repository performance. They and their laboratory equipment will not be available to chase down the inevitable ambiguities uncovered by the regulator. Killing the license review means that we may never know what it takes to achieve a repository license.

Perhaps Secretary Chu realizes that a positive finding by the Nuclear Regulatory Commission that Yucca Mountain is qualified to meet the standards for protection of the public and environment would force the administration to admit that they had put politics before science, in conflict with their stated policy.

With regard to the social sciences studies and concepts reviewed here, what are we to make of the situation? It appears that we have been offered some necessary but not sufficient suggestions.

Social and psychometric models of risk perception are useful descriptive science. The work in risk perception helps in anticipating the intuitive issues in the public mind and tells us that objective statistical risk estimations, though useful in discussions, will never be entirely convincing. But there are no prescriptions for designing public acceptance into pre-packaged hazardous facility proposals. There are suggestions for cautious consensus-building processes, but these suggestions are offered without assurances that they are sufficient to the challenge. Since we have no recent examples of national consensus on important issues, any hope for consensus on nuclear waste that would hold up to the siting challenge seems futile.

Whether public aversion of radioactive waste is a result of fear, neglect of probabilities, distrust of the experts or their science, or just resentment of unfair burdens, it seems in any case to be an expression of deeply ingrained human nature. Evidence shows this aversion to be common within both the lay public and even among experts in fields non-specific to nuclear waste or decision and risk analysis. The experts who trust probabilistic risk assessment as applied to nuclear waste appear to have muted the usual intuitive responses by extensive conditioning through education and topic-specific experience. Perhaps the only path to public acceptance may be the impracticable one of making experts of all the voting public.

Any new technological options suggested by the Blue Ribbon Commission will still need to site facilities for treatment, packaging and interim storage. Whether in the form of spent fuel or processed waste, these materials will still need transporting on highways or rails, through small towns, suburbs or cities. The materials will still be radioactive nuclear waste, with all the baggage of worrisome imagery and repellant emotion that the psychologists have found so prevalent in the lay public. So what is the point of new technological options? Of course, the Commission may suggest extending on-site monitored retrievable storage, and perhaps the plant owners can oblige; but will another nuclear plant ever be built if the local populace understands that the spent fuel will forever stay on site in a storage mode that cannot be assured safe for more than 100 years?

There is compelling evidence that public opposition, driven by worry and resentment, can become a potent political force, and that opposition cannot be avoided so long as the repository project is experienced as an unwarranted imposition by outsiders whom they do not trust.

As regards the Yucca Mountain project, it is rather late to remove the stain of imposition. Most in Nevada are aware of the history of court rulings and Congressional statutes. One possibility for reversing public opposition would be to find some trusted authorities (non-DOE) to make a convincing case that the imposition is not unwarranted. Whether or not the Nevada public would be swayed by a clearly-presented, strong scientific case, joined to the national interest, cannot be predicted. If attitudes have hardened, perhaps not, but is it not worth making the effort? Clearly, that effort should await a positive finding of safety from the Nuclear Regulatory Commission review of the license application, assuming it is allowed to proceed. If the US NRC finding is negative for Yucca Mountain, there is no case to be made. Political withdrawal of the DOE license application may forestall even this attempt to salvage something from the wreckage.

The Swedish experience is informative by comparison.

The Swedish program was supported, early in its formative period, by the credible and intensive public outreach efforts of KASAM, the independent academic advisory body. KASAM was chartered in 1985. Though some topical R&D had been underway, Sweden didn't start its site feasibility studies until announced in 1992 by a letter from SKB to all of the municipal councils (Sjöberg, et al, 1999). Prior to that, there had already been public meetings, issue information documents and seminars on the ethical issues to be faced (KASAM 1988). Only a few municipalities declined to participate from the start. The U.S. government made much the same announcement in a letter to the states in 1976, without the prior independent public outreach and with a very different, mostly negative, reception.

One must be cautious, however, in translating the Swedish experience to the U.S.A. Outreach and consensus building in Sweden is a more manageable challenge than in the U.S. Start with the fact that Sweden has 9.1 million citizens living in 290 locally governing municipalities. This compares with 300 million population of the U.S. distributed over 25,000 cities and towns (Census, 2000). Sweden also has a much more homogeneous demographic: 91 percent Scandinavian, 87 percent belonging to the Church of Sweden (Lutheran), 99 percent literacy (CIA World Factbook 2010). Sweden's municipalities, which are about the size of average Texas counties, do not have the same degree of political and legal autonomy as do the U.S. states. The Swedish psychologist, Lennart Sjöberg, observes (that) "Sweden is a relatively well integrated society with a long history of peace and successful resolution of conflicts, both internal and external.

Authorities are considered, by the public, to be competent and non-corrupt, even if (elected) politicians are seen in a different light." (Sjöberg 1999)

Public outreach was more ad hoc than strategic throughout the early history of the U.S. waste repository programs. Following the abandonment of Lyons, Kansas site, the US Atomic Energy Commission enlarged its studies of disposal alternatives in 1972 to include other salt formations within the United States, rock types other than salt, and alternatives to geologic disposal (Lomenick 1996). The AEC allotted only a few months for the study to identify potential sites for pilot repositories, and allowed one year more for final selection. The study was led by ORNL, with assistance from the USGS. Out of this effort, emerged the Waste Isolation Pilot Plant (WIPP) site near Carlsbad, New Mexico.

The preliminary studies were all done with existing data (no field work), and the existence of the screening effort was not judged worthy of general public outreach. However, the expertise of state agencies and universities were tapped fairly early in the process. As studies progressed on the geology near Carlsbad, New Mexico, local and state elected officials were briefed (Lomenick 1996). The literature is not clear on the point, but it is likely that officials were briefed before any field work commenced.

The US first announced a nationwide screening to identify potential sites in November 1976, with a letter to the Governors of 36 states, those that had any prospect at all of favorable conditions. At that time, very little of the social science research reviewed here had been done. ERDA had learned to avoid blind-siding elected officials, however, and elaborate measures were undertaken to assure simultaneous notifications. There was an explicit belief that the larger screening effort, envisioning ultimately 6 distributed repositories, would be viewed as a fair sharing of the burden of disposal (Lomenick 1996). ERDA was greatly surprised at the widespread negativism in the feedback from state governments (Carter 1987, page 131 and Metlay 1985).

Luther Carter, in his book *Nuclear Imperatives and Public Trust* (Carter 1987), devotes an entire chapter to describe nuclear power as a "technology ahead of itself" due to aggressive promotion of fission reactor development and commercialization with only scant attention to fission product waste management and disposal. The more successful (thus far) Swedish spent fuel disposal program suggests that the science and technology of U.S. waste disposal program got ahead of itself by scant (or at least belated) attention to cultural and psychological preconditions for public acceptance. Entwined with this failure to prepare the soil before planting, it is likely that ERDA and DOE program managers simply did not realize the degree to which AEC missteps had blighted their credibility beyond recovery. Their best public outreach efforts would be dissolved by corrosive recollections of Hanford tank leaks, releases from the Maxey Flats LLW burial trenches, the Rocky Flats facility fire, and other incidents.

The social sciences and the Swedish experience thus tell us that there were institutional and programmatic deficiencies in the geologic programs undertaken by US DOE and its predecessor agencies. Mostly, these deficiencies were in the area of timely public outreach and, especially, in cultivating a useful degree of nationwide public consensus on what needed to be done to manage fission product waste.

It is worth noting, however, that none of the social science literature cited in this paper recognized the public outreach that <u>was</u> done in the early ERDA and DOE periods. Public outreach efforts in the DOE were limited in scope and constrained in content by concerns that someone somewhere would consider it "propaganda." A polished film clip or video dealing with the beliefs and attitudes feeding the risk aversion, taken directly from the psychological research, would display the advantages of nuclear power, the cautious handling of spent fuel, and the national public investments that have allowed Las Vegas to flourish as a part of the American community. Such an outreach tool would have never been allowed. The measure of acceptable content seemed to be that it consist of dull, scientific verbs and nouns: no adjectives, please, lest the message be construed as advocacy.

This author personally appeared before over 100 public meetings with ordinary citizens in communities throughout the states being studied. On behalf of DOE, the Battelle Memorial Institute in Columbus, Ohio hosted Annual Information Meetings for years. These conferences afforded unrestricted opportunity for state officials (executive and legislative) to meet (unscripted) with leading program scientists and managers to confirm personally what were the objectives, the rationale and findings of studies in their jurisdictions and throughout the country and to comment on any aspect. The program in those days was repeatedly plagued by conspiratorial delusions that ERDA or the DOE was secretly pumping waste underground when drill rigs showed up to take core samples. Occasionally, elected officials and local media would lend credence to such accusations. The conferences helped to immunize state and local officials against such nonsense.

Aside from those efforts, it can be said that the DOE has relied too much upon the NEPA model for public outreach. NEPA, the National Environmental Policy Act (Public Law 91-190), requires any Federal agency to prepare either an Environmental Assessment or Environmental Impact Statement for any action (with some few exemptions) that might affect environmental quality. The agency is required to present its proposed action and any reasonable alternatives. An opportunity for public review and comment on a draft EIS is to be provided, and the agency must assess and consider those comments before making its final decision on how to proceed. Even if this process is scrupulously followed, and with every intention to weigh relevant public comment, the process is distant and formal. Value-laden perceptions and judgments may be misunderstood or neglected, and the implementing agency is not viewed as impartial. Given these deficiencies, the NEPA model just does not carry the same credibility and legitimacy of the Swedish approach.

It must be said that even the NEPA approach to venting the fundamental options for civilian HLW management was poorly timed. The Draft EIS on Management of Commercially Generated High Level Radioactive Waste was not issued for public comment until April 1979. That EIS compared deep-mined geologic isolation, as the proposed approach, against alternatives such as space disposal, deep seabed sediments, separation and transmutation, and deep borehole emplacement (US DOE 1980). Prior to the finalized EIS, DOE and other federal agencies had properly referred to geologic disposal as an interim strategy and funded studies of other options, so the timing could be considered legally sufficient; but it certainly didn't contribute any readiness for the public and political leaders of states to accept involvement in the search for suitable sites. Had this EIS been done in 1971, and revisited after subsequent R&D expanded the knowledge base, then the NEPA process might have played a more constructive role in shaping some consensus on national purpose. As it was, many observers took to calling the DOE process "Decide, Announce, Defend."

5.1 Starting Over

Some are suggesting that the U.S. should just reorganize everything and start over, buying time by expanding capacity for interim storage (Slovic, et al, 1991; Easterling and Kunreuther, 1995; Flynn, et al, 1995). That is equivalent to putting the U.S. effort back 34 years or so, back to 1975. Clearly, then, another generation will pass. Everyone now working in the field will be retired. The nuclear science and engineering expertise of the country is already withering, due to the long de facto moratorium on nuclear power expansion (IAEA 2004). The sudden suspension of the Yucca Mountain project is already seeing dispersal of management and science expertise. How long will it be before young geologists hydrologists, and geochemists will be willing to hitch their career prospects to geologic disposal, when their life's work can so demonstrably be nullified by political decision? What song are we going to sing in the halls of the United Nations, the IAEA and the OECD to explain our abrogation of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management? Are we going to denigrate geologic disposal to the host of nations still headed down that path?

If it is decided that the U.S. should start over, despite the costs and risks on every front, is there any assurance of greater success? Can we get a better site for disposal, can we site any new interim management facilities and, more importantly, can we achieve public acceptance? We need to remember the findings of social science research that radioactive waste conjures up more virulent aversion than any other substance, and that transport corridors and facilities, whether for treatment, storage or disposal, will be bitterly resisted (Slovic, et al 1991).

This may well be a "pay me now or pay me later" situation. Instead of technical options, let's look at the social and institutional options. If what we have seen of the public reaction to Yucca Mountain is immutable human nature, then we have three choices: use Federal preemption now, on Federally-owned land in an inhospitable desert, attempt it later, perhaps on private land, or just bequeath the fission product waste in all its forms to our great-grandchildren in interim storage modes that are suffering the ravages of time.

The Presidential Blue Ribbon Commission is chartered to investigate and recommend new technological approaches to HLW and SNF management. Unless they can conjure up a technology that obviates any transport of these radioactive materials and requires no siting of treatment, storage or disposal facilities, they will have done nothing to advance the probabilities of public acceptance and political will. They will not have addressed the central problem.

If we start over on the disposal problem, several time-tested principles of project management, fiscal risk management, and fiduciary responsibility will have to be abandoned. The investors in a nuclear waste facility, whether for treatment, storage or disposal, will have to share decision making with stakeholders who are bringing none of the money to the table. But they are bringing a trump card: they can politically block the facility if they are sufficiently energized to do it. Costs will be incurred for matters that are justified only by stakeholder demands, matters of perception and not engineering substance. There is the added complication that the negotiation of public acceptance will require technical data bearing on safety that can only be produced by significant investment. Those early dollars are completely at risk of a possibly implacable public opposition.

If we start over on the disposal problem, the central challenge highlighted in the findings of social science research is the necessity for achieving and holding a stable social matrix of trust and consensus on the way forward. Institutions must be redesigned and repopulated so as to leave behind the historical baggage of failures and secrecy dating back to the AEC wartime urgencies. Not that this will be sufficient, it nonetheless appears necessary.

We face now a situation in which the political will does not exist to exert preemptive national powers to site a repository in the face of local opposition. This is despite the site being on Federal land that is already irredeemably contaminated by decades of nuclear weapons testing. If Federal preemption were to be abandoned, the first step of a new effort down a new path would be to articulate the intention of achieving the willing consent of a majority of stakeholders wherever facilities are to be sited.

This would be an irreversible gamble, and one that might doom the entire enterprise to inevitable political failure. All it takes to fuel unwavering opposition is the belief that property values will decline throughout a community or a county stigmatized by the repository. Even if locals are fully convinced that the proposed facility is safe and offers good jobs, they have to worry that others elsewhere may not be convinced and will take their commerce elsewhere. Stigma is an attitude fabricated from beliefs that can be imagined out of nothing but rumor. It is self-fulfilling: the more it is discussed and anticipated, the more it becomes a reality.

The level of trust that the facility proponents must earn and sustain is very difficult to achieve. There will always be some element of criticism, even for the most responsibly managed and designed proposal. That criticism will feed doubt. The proponents will always be in the position of having to assure the audience that there is no fire in the theater, while every single member of that audience thinks "well, maybe so, but just in case, my wisest precaution is to run for the exits." As long as there is research to be funded, consultant fees to be earned, and donations to be had, criticism and doubts will be forthcoming, along with the slight whiff of fear.

The public's anxiety about the repository program is increased by the widespread lack of familiarity with the thought processes that occur at the frontiers of science. High school and even early college presentations of science focus on long-settled validated laws and mathematical certainties. Relatively few of the general public appreciate that the frontiers of science are argumentative, with incongruous data and discordant hypotheses in contest to advance the frontier into ever-larger domains of understanding. The repository projects around the world are pushing the geosciences into just such frontiers. The emergence of new data and struggles of interpretation are a normal environment for the scientists involved, but a crisis of confidence for many of the onlookers. Bureaucracies like the US DOE are aware of these public sensitivities, answerable to many constituencies, and anxious themselves to avoid the taint of chaos in their programs. Unfortunately, this can sometimes lead to counterproductive efforts to belittle or camouflage the disputes rather than attempts to calmly explain the lurching march of science.

Another big contributor to instability in the public support of nuclear and some other industrial projects are the "spoilers" who will twist any phrase, misapply any quote and persist in long-discredited indictments, all in defense of a surpassing certainty that their selected nemesis is evil and must be stopped.

Colglazier, reporting on a 1979 Aspen Institute conference, observed that environmental activists (at that time) were not particularly interested in consensus-building because they counted on an informed citizenry opposing the siting of waste facilities and thereby demanding an end to nuclear power (page xviii). Easterling and Kunreuther (1995, page 141) observe that there are individuals who have moral or ideological qualms about nuclear power and that those individuals "may view geologic repositories as inappropriate regardless of how much might be achieved in the way of improved storage of spent fuel."

It takes only a few voices that are willing to delay and obstruct waste disposal programs in the service of a higher calling (elimination of nuclear power and possibly all nuclear technology). Driven by an antithetical world-view, a few implacable opponents, speaking from conviction, can incite considerable public consternation on this topic.

No one is offering guarantees here.

Appendix A: Alarmist Warnings of Radioactive Waste

As a means of getting the reader's attention, Thomas Cochran of the Natural Resources Defense Council (NRDC – an organization of environmental interveners) has said that, as a crude measure of the toxicity of fission products, in order to meet existing federal drinking water standards it would take over 60 million billion gallons of water to dilute the fission product wastes accumulated in the U.S. by the year 2000 (Cochran, et al 1979).

That's an impressive image, but not unique among industrial toxins, and not relevant to any HLW disposal regime considered anywhere in the world.

In 2000, the world cumulative industrial-age anthropogenic arsenic production was 4.53 million metric tons. The worldwide coal and petroleum industries accounted for 27% of that industrial-age gross arsenic production. The rank-ordered cumulative anthropogenic sources follow the order: mining production > generated from coal > generated from petroleum (Han, et al 2003). All of that arsenic is still around in the biosphere somewhere. Unlike radioactive waste, it does not decay: it has an infinite half-life.

The Maximum Contaminant Level (MCL) for Arsenic in US drinking water is 0.010 ppm, according to the US EPA standard (US EPA 2001). A simple division results in the fact that it would require 4.53 10^{17} kg of water to dilute all the Arsenic loose in the world down to potable standards. Since 1 Liter of water weighs 1 kilogram, one US gallon of water weighs approximately 3.785 kilograms. Therefore, to meet existing federal drinking water standards, it would take about 1.2 10^{17} gallons of water to dilute the worlds inventory of Arsenic to safe levels. That's 120 million billion gallons, twice the amount cited for safe dilution of the world's fission product wastes.

It's not the purpose of this brief comparative analysis to diminish the hazards posed by spent fuel or the fission product wastes therein. It is simply to point out that the choice of dilution in drinking water, as a descriptor of the hazard of fission product waste is deceptive one. Whatever the intent might be, that descriptor serves the purpose of arousing readers to feel and fear what sounds like a uniquely terrifying risk. (God help us, will there be any potable water left on the planet?) It offers a readily recalled, specific image to brood upon, even though that image is completely beside the point.

Dilution, though used for industrial stack emissions into the atmosphere, is a bad idea for all kinds of hazardous substances, not least among them spent fuel and High Level Waste from reprocessing. And no one anywhere in the world is proposing the scattering of spent fuel to the four winds. Agricultural uses and various stack emissions are doing precisely that with the comparably toxic Arsenic, but that just goes to show that toxic substances may be carelessly, even recklessly, released into the environment with effects that are less than disastrous poisoning of the world's population.

Appendix B: A Word of Caution About Perceived Risk

These thoughts are extracted from Cross (1992 and 1997)

The significance of environmental values is highlighted in prevailing controversies pitting public perceptions of risk against more scientific probabilistic measures. The probabilistic measures are not infrequently on the side of the "polluters." While public risk perceptions were once cavalierly derided as ignorant, they now are often lauded as richly value laden. (Paul B.) Thompson suggests that a "reasonable person's concept of risk, vague as it is, is *better* suited to the regulatory requirements of risk management than are probabilistic concepts." Scientific probabilism, sometimes criticized for inaccuracy, is more commonly rejected as impoverished in its lack of normative values.

Perceived risk centrally differs from scientific method risk in that it may more readily be manipulated. Consider an unusually hazardous pesticide that causes one thousand deaths per year. The producers of the pesticide may hire consultants, contribute to politicians, and take other measures to obscure the true risk of their product and maintain its production. Ultimately, though, objective truth is on the side of the regulators who can demonstrate the un-safeness of the pesticide. Of course, such scientific truth does not always win out in our present regulatory system, which can be slow and uncertain. The substantial amount of strict environmental regulation that has been adopted does demonstrate that powerful economic interests will often lose in a battle against scientific data. If industry truly dominated regulatory estimates of risk, it seems unlikely that government would have adopted rules compelling tens of billions of dollars in annual compliance costs.

In a regime of perceived risk, however, scientific data is not enough -- that data must be presented to the relevant perceivers in a convincing manner. The struggle becomes one over what advocacy group can best affect public perception. Framing the struggle in this way gives an enormous advantage to groups possessing economic and other sources of social power and hurts disenfranchised groups. Powerful economic interests cannot change objective truth, but they can change public perception. Money and media are influential.

If Lobbying is now superior to science in determining scientific fact, the day can't be far off when public opinion polls will decide what is scientifically true. And economically true as well.

It is ironic that advocates of risk perception typically defend their perspective as a counterweight to empowered elites who supposedly control scientific risk assessment. One author, for example, contends that "the issue is not risk, but power; the power to impose risks on the many for the benefit of the few." This perspective may have some limited truth in some contexts of today's regulatory world, which is predominantly based upon scientific method risk assessment. Yet it is inordinately naive to believe that a shift toward perceived risk would cause the elites to surrender their interests. It seems far more likely that the empowered elites would redeploy their resources in order to manipulate public perceptions of risk more effectively.

Perhaps the most persuasive defense of objective reality and the scientific method can be found in the seemingly alien field of literature. Few tales of oppression are more compelling than "1984," and George Orwell's authoritarian Big Brother recognized the need to destroy the concept that reality is something objective and testable. To dominate and oppress, Big Brother propagated the perception that neither words nor reality had real external meaning, declaiming that "reality exists in the human mind, and nowhere else." Totalitarians find such minds far more malleable than the authentic scientific method.

The above criticism of reliance on risk perception does not imply that democratic governments should ignore public values and perceptions of risk entirely. Such a contention would be hopelessly naive in a democracy. Unquestioning deference to the conclusions of scientists is also potentially counterproductive. History shows that perceptions or opinions of government scientists, if not science itself, can be controlled or manipulated by authoritarians much like the perceptions of the public. Action should not be exclusively driven by government scientists. The dangers of risk perception do caution that the pursuit of truth through the scientific method should be the object of governance. The people need not be foreclosed from risk determination, but reality (as ascertained through the scientific method) must remain as a check on the powers of government to act on public perceptions.

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